Final
Evaluation of Groundwater Treatment Alternatives
RSA-95 and RSA-96
Redstone Arsenal
Madison County, Alabama

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Delivery Order 0004
Contract No. DACA21-96-D-0018
IT Project No. 772650

August 1999

Table of Contents

Page

List of Tables ii
List of Figures ii
List of Acronyms iii
Executive Summary ES-1
1.0 Introduction 1-1
1.1 Site Conditions 1-1
1.2 Basis of Evaluation 1-3
1.3 Estimation of Contaminant Concentrations in Treatment Streams 1-4
1.4 Technology and Process Screening and Selection of Remedial Technologies 1-5
1.4.1 Technology Screening 1-5
1.4.2 Process Options for Ex-Situ VOC Destruction 1-6
1.4.3 Process Descriptions 1-7
1.4.4 Cost Summary Comparison 1-9
2.0 Evaluation of Treatment Alternatives 2-1
2.1 Carbon Adsorption as the Primary Treatment Technology 2-2
2.2 Air Stripping as the Primary Treatment Technology 2-2
2.3 Chemical Oxidation and Polishing by Air Stripping 2-3
2.4 Summary 2-4
3.0 Conclusions and Recommendations 3-1
4.0 References 4-1
Appendix A - OU-10 Pilot Test Flow/Concentration Data
Appendix B - OU-10 Treatment System Performance Calculations
Appendix C - Cost Comparison Summary

List of Tables

Table	Title	Follows Page
1	Extraction Well Construction Details and Suggested Pumping Rates, Groundwater Extraction at RSA-95 and RSA-96	1-2
2	Extraction Well Groundwater VOC Concentrations, Groundwater Extraction at RSA-95 and RSA-96	1-3
3	Recovered Chlorinated Solvent Mass in Groundwater by Extraction Well, Groundwater Extraction at RSA-95 and RSA-96	1-4
4	Contribution of Recovered Chlorinated Solvent Mass by Extraction Well, Groundwater Extraction at RSA-95 and RSA-96	1-4
5	Contaminants and Concentrations in Degreaser Sites, Groundwater Treatment Stream, RSA-95 and RSA-96	1-5
6	Contaminants and Concentrations in Groundwater Treatment Stream, RS715 at RSA-95 and RS593 and RS730 at RSA-96	1-5
7	Physical Parameters and Coefficients and Evaluation of Technologies for Groundwater Treatment Alternatives	2-1
8	Allowable Levels of Organic Compounds in Treatment Stream	2-1
9	Treatment System Evaluation Summary, Groundwater Extraction at RSA-95 and RSA-96	2-3

List of Figures

Figure	Title	Follows Page
1-1	Site Location Map RSA-95, RSA-96, RSA-97 Degreaser Sites	1-1
1-2	Extraction Well Locations, Treatment Plant Location, Showing TCE Groundwater Plume RSA-95 and RSA-96 Degreaser Sites	1-1
1-3	RSA-95 Estimated Bedrock Potentiometric Surface Due to Pumping at 3 Wells	1-3
1-4	RSA-96 Estimated Bedrock Potentiometric Surface Due to Pumping at 3 Wells	1-3
2-1	System Process Flow Air Stripping/Vapor Phase Treatment Alternative	2-3
2-2	System Process Flow UV Oxidation/Air Stripping Treatment Alternative	2-3

List of Acronyms

GAC	granular activated carbon
gpm	gallons per minute
IRA	interim remedial action
lb/day	pounds per day
LGAC	liquid-phase GAC
NPDES	National Pollutant Discharge Elimination System
OU	Operable Unit
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
RSA	Redstone Arsenal
TCA	trichloroethane
TCE	trichloroethene
UV	ultraviolet
VGAC	vapor-phase GAC
VOC	volatile organic compound

Executive Summary

Purpose. This decision document describes the selected action to reduce dissolved-phase trichloroethene (TCE) and trichloroethane (TCA) mass at two Operable Unit (OU)-10 degreaser sites at Redstone Arsenal (RSA) and was chosen in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act as amended by the Superfund Amendments and Reauthorization Act of 1986, the National Contingency Plan, Resource Conservation and Recovery Act, and AR 200-1, as applicable. The selected Operable Unit-10 Degreaser Sites interim remedial alternative is groundwater extraction and treatment, part of an established presumptive response strategy for groundwater contaminated with volatile organic compounds (VOC) (EPA, 1996). The purpose of the interim remedial alternative is TCE mass removal from the OU-10 degreaser spill sites with the objective of reducing mass at the spill sites hot spots.

Site Risk. Preliminary results of the remedial investigation at OU-10 degreaser sites RSA-95 and RSA-96 revealed concentrations of the chlorinated solvent TCE in residuum and bedrock aquifer above Federal safe drinking water standards. The release of the TCE occurred during former rocket motor manufacturing operations at these sites. The concentration of TCE in groundwater at sites RSA-95 and RSA-96 is considered to exceed human health based criteria if off-site migration were to occur and impact potential public drinking water supplies. Potential migration of the TCE impacted groundwater to surface water bodies would also degrade ecological conditions and provide an exposure pathway to human health risk, potentially exceeding the acceptable risk threshold.

Remedial Alternatives. Groundwater is to be extracted and treated to remove VOCs as part of an interim remedial action (IRA) at two former degreaser facilities, RSA-95 and RSA-96. The goal of the IRA is TCE mass removal from the bedrock aquifer in order to prevent off-site migration of the contaminated groundwater and to reduce the relative risk at the degreaser sites hot spots. Groundwater extraction and treatment is an accepted presumptive remedy for VOC contamination. Groundwater will be pumped from each of the degreaser sites to a single treatment facility, where it will be processed to meet discharge limitations.

Public Involvement. This interim remedial alternative was selected by RSA, with support from the Alabama Department of Environmental Management and the U.S. Environmental

Protection Agency. At the time of publication of this document, public involvement on the interim remedy selection process has not been initiated.

Declaration. The selected remedy is protective of human health and the environment, attains federal and state requirements that are applicable or relevant and appropriate to this interim remedial action, and is cost effective. This remedy satisfies the statutory preference for remedies that employ treatment that reduces toxicity, mobility, or volume as a principal element, and utilizes permanent solutions and alternative treatment technologies to the maximum extent practicable.

1.0 Introduction

IT Corporation has been retained by the U.S. Army Corps of Engineers under the Total Environmental Restoration Contract DACA21-96-D-0018, Modification 1, Delivery Order Number 0004, to develop and evaluate alternatives for groundwater remediation and treatment at Redstone Arsenal (RSA), Madison County, Alabama. This decision document describes the selected action to remove mass at the Operable Unit (OU)-10 degreaser sites at RSA and was chosen in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act as amended by the Superfund Amendments and Reauthorization Act of 1986, the National Contingency Plan, Resource Conservation and Recovery Act (RCRA), and AR 200-1, as applicable.

1.1 Site Conditions

Preliminary results of the remedial investigation (RI) activities at OU-10 degreaser sites RSA-95, RSA-96, and RSA-97 indicated elevated concentrations of the chlorinated solvent trichloroethene (TCE) and other chlorinated VOCs in residuum and bedrock aquifer. Figure 1-1 shows the location of sites RSA-95, RSA-96, and RSA-97 within OU-10 and RSA. The release of the TCE occurred during the rocket motor manufacturing operations at these sites. The concentration of TCE in groundwater at sites RSA-95 and RSA-96 is considered to exceed human health-based criteria if off-site migration were to occur and impact potential public drinking water supplies. Preliminary review of data from RSA-97 indicated that groundwater concentrations are much lower than at the other degreaser sites, and will not be addressed in this document. Recommendations for an IRA for RSA-97 will be presented in a report of findings at a later time.

Potential migration of the TCE impacted groundwater to surface water bodies would also degrade ecological conditions and provide a potential exposure pathway to human health risk possibly exceeding the acceptable risk range. Figure 1-2 shows the distribution of TCE in groundwater at RSA-95, RSA-96, and adjacent areas to OU-10.

Groundwater sampling at RSA-95, RSA-96, and RSA-97 was conducted during May and June 1998 as part of RI activities at RSA-95, RSA-96, and RSA-97. Results from RSA-95 and RSA-96 were used in developing the treatment alternatives and to perform the first preliminary estimates for the concentrations of volatile organic compounds (VOC) in the proposed interim

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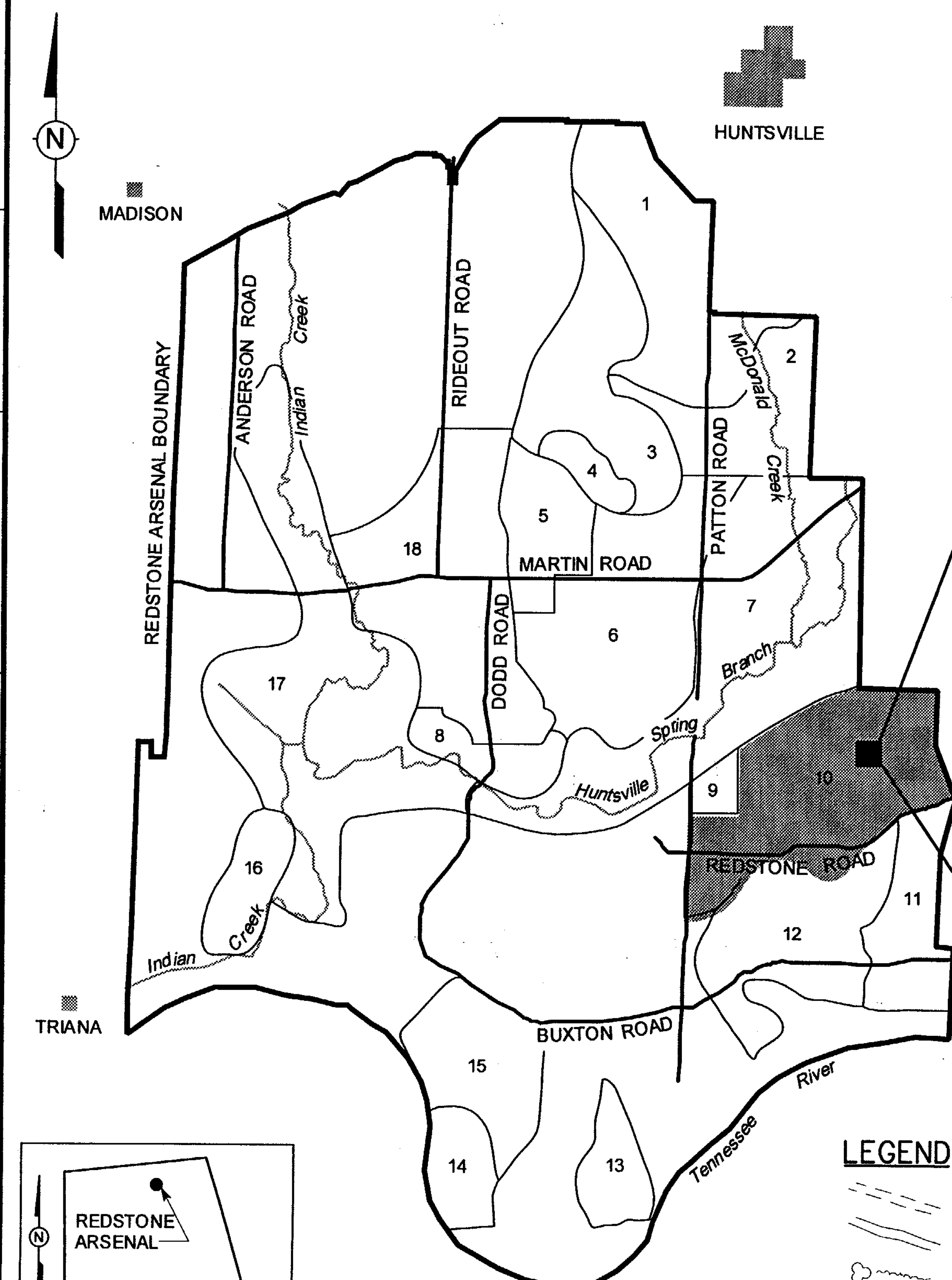

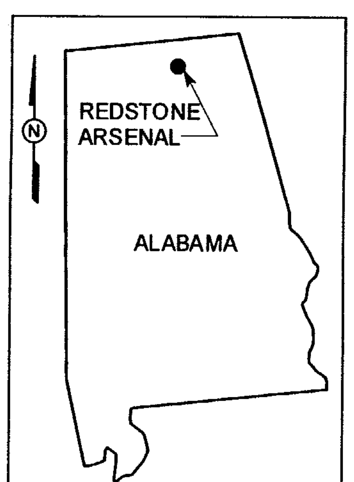

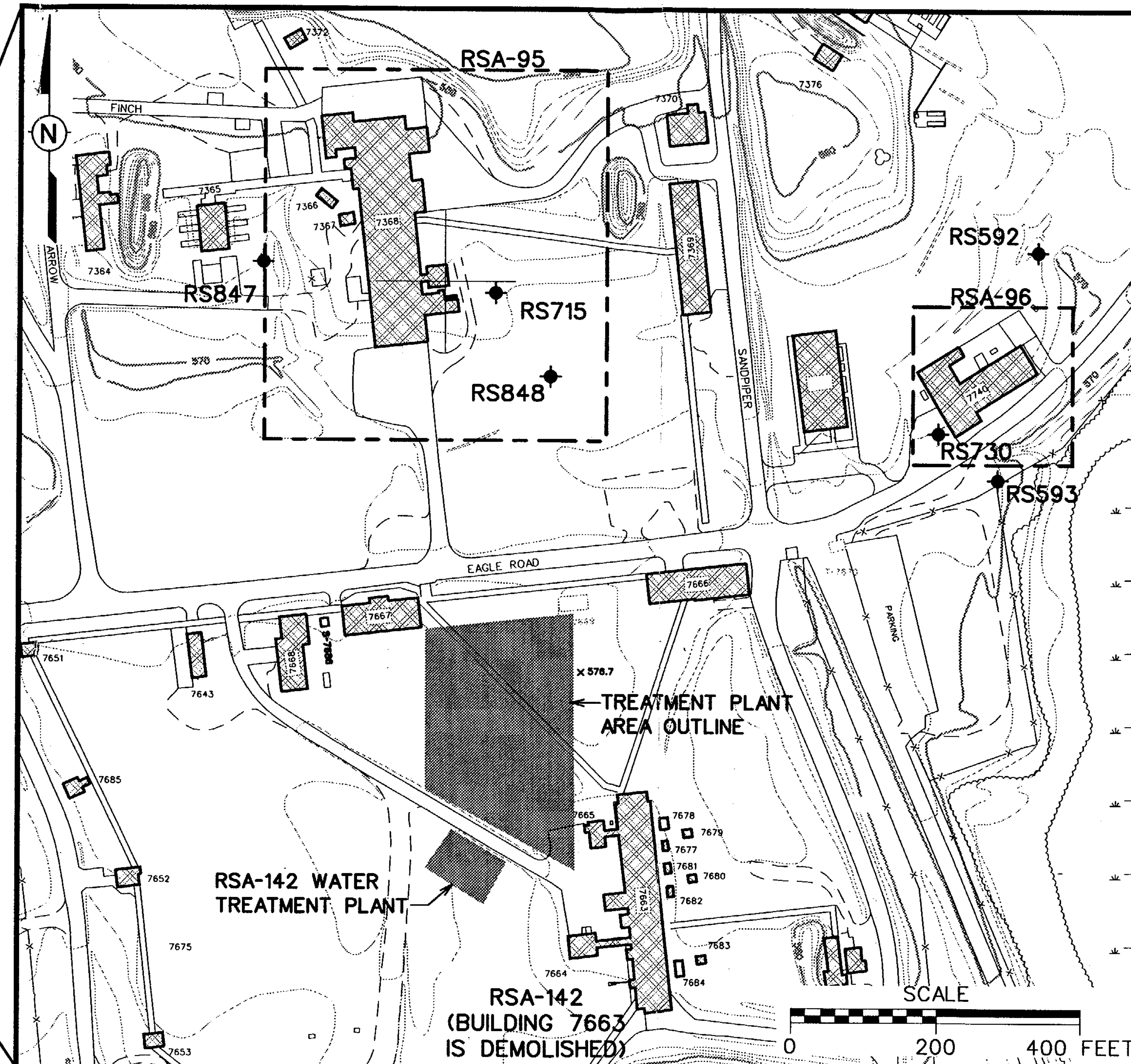

LEGEND

- UNIMPROVED ROADS AND PARKING
- PAVED ROADS AND PARKING
- TREES / TREELINE
- CREEK
- FENCE
- 650 TOPOGRAPHIC CONTOURS (FT-MSL)
- RSA SITE BOUNDARY
- 10 OPERABLE UNIT BOUNDARY
- EXTRACTION WELL LOCATION

FIGURE 1-1
SITE LOCATION MAP
RSA-95 AND RSA-96
DEGREASER SITES

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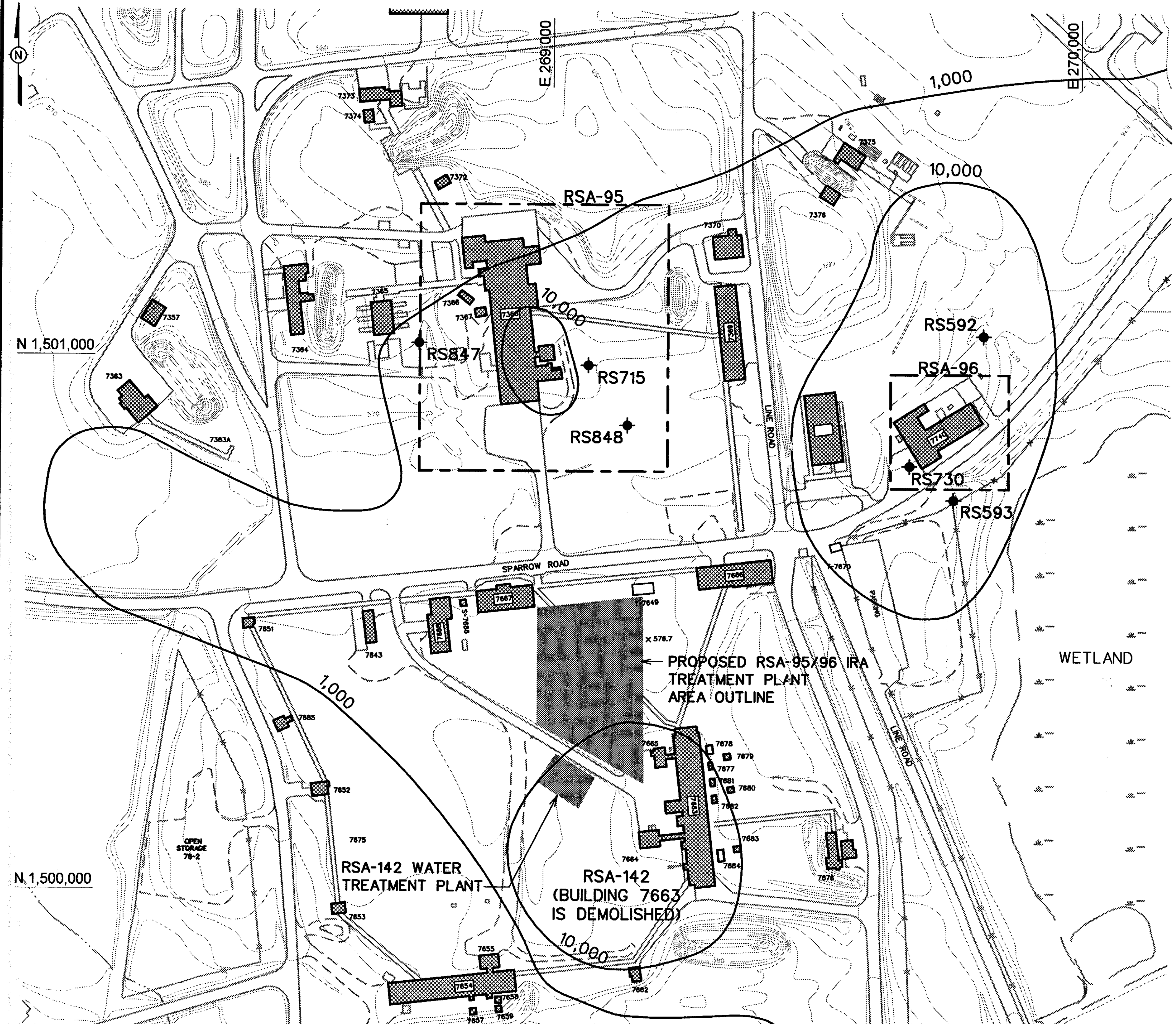

LEGEND

◆ EXTRACTION WELL LOCATION

NOTES

TCE CONTOURS IN ug/L

SCALE

0 200 400 FEET

FIGURE 1-2
EXTRACTION WELL LOCATIONS, TREATMENT PLANT LOCATION, SHOWING TCE GROUNDWATER PLUME RSA-95 AND RSA-96 DEGREASER SITES

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remedial alternative treatment system influent. Samples were analyzed for VOCs by U.S. Environmental Protection Agency Method 8260A. Methylene chloride was also reported from the samples, but is considered a laboratory contaminant and is eliminated from this evaluation. Preliminary step-drawdown pumping tests conducted at RSA-96 in August 1998 indicated the wells would probably sustain pumping rates between 50 and 100 gallons per minute (gpm) (IT, 1999). A centrally located treatment system for a proposed interim remedial alternative (IRA) treatment system would have an influent feed rate much higher than previously anticipated.

Extraction wells were installed at both RSA-95 and RSA-96 to support the proposed interim remedial action (IRA) for mitigation of groundwater contamination by chlorinated solvents at these sites. Two wells, RS592 and RS593, were installed at RSA-96 as part of a supplemental remedial investigation in May 1998, and one additional well, RS730 was installed in January 1999. Three wells were installed at RSA-95 (recovery wells RS715, RS847 and RS848) between October and January 1999. Extraction well construction details are provided in Table 1. The wells are either 6 or 8 inch diameter, with stainless-steel screens and schedule 80 PVC risers.

Variable rate pumping tests were conducted at extraction wells installed at RSA-95 and RSA-96 in July and August 1998. A pilot test program conducted during March through April 1999 on the six recovery wells at RSA-95 and RSA-96 evaluated concentration versus variable rate pumping data (IT, 1999). Proposal pumping rates are given in Table 1. The well yield and groundwater concentration data was used in developing the design data for this document. A summary of the pilot test groundwater concentration data is found in Appendix A. The step-drawdown tests were conducted to determine the maximum discharge at which the well can be pumped without lowering the groundwater level below the top of the weathered limestone bedrock (epikarst). However, the maximum pumping rate for the pilot study was limited by the capacity of the temporary treatment system used to treat the pump test water before discharge to the sanitary sewer, and no individual well was pumped at a rate that would bring the water level into the epikarst.

Most of the recovery wells, except RS715, exhibited capacities that exceeded the maximum pilot test pumping rates. Pumping rates used in the calculations presented in this document were obtained from analysis of the variable rate pumping tests. The pumping rates projected for each well will capture the most contaminated portion of the plumes. Some mass removal will occur over a wide area of the plume. The selected pumping rates at outlying wells will prevent dilation of the plumes. Also, these rates will not draw the water level to the top of the bedrock, but will

Table 1

Extraction Well Construction Details and Suggested Pumping Rates
Groundwater Extraction at RSA-95 and RSA-96
Redstone Arsenal, Madison County, Alabama

Well	Casing Diameter (inches)	Boring Diameter (inches)	Screen Interval (ft)	Well Depth (ft)	Suggested Pumping Rate (gpm)
RSA-95					
RS715	8	12	71-91	91	60
RS847	8	12	18-48	50	30
RS848	8	12	22.5-52.5	57	35
RSA-96					
RS592	6	11	49.9-80	80	25
RS593	6	15	28.5-64.5	65	100
RS730	8	12	35-65	65	100

gpm - Gallons per minute.
ft - Feet measured from ground surface.
Pumping rates are the suggested rates to be used in the IRA.

still generate a significant bedrock aquifer groundwater cone of influence. Composite bedrock potentiometric surface contour maps due to pumping at the maximum rates are shown for RSA-95 and RSA-96 in Figures 1-3 and 1-4.

Groundwater sampling was conducted at the extraction wells at several times. During the pumping tests samples were collected every 2 hours over a 24-hour period. Concentrations in the last sample collected from the pumping test was used in evaluating the groundwater treatment alternatives. Because of the high concentrations of TCE, samples were analyzed at high dilutions, typically 20 to 200 times. Groundwater concentrations used in these calculations are given in Table 2. The analytical results from each sampling event are provided in Appendix A.

1.2 Basis of Evaluation

Groundwater is to be extracted and treated to remove VOCs as part of an IRA at two degreaser facilities, RSA-95 and RSA-96. The goal of the IRA is; contaminant mass removal from the bedrock aquifer in order to reduce contamination in groundwater, reduce potential for off-site migration of the contaminated groundwater, and to reduce the relative risk at the degreaser sites hot spots. The goal of the IRA is not to control contaminant discharge or plume migration. The selected IRA is to be considered as a candidate remedial technology for the final remedy of OU-10.

Groundwater extraction and treatment is accepted as part of the presumptive response strategy for contaminated groundwater. It is recommended that groundwater is pumped from each of the degreaser sites to a single treatment facility, where it will be processed to meet discharge limitations.

Standard criteria chosen for evaluating the effectiveness of the treatment technologies in meeting discharge criteria for either the treatment system effluent water or vapor stream are:

- Permitted National Pollutant Discharge Elimination System (NPDES) discharge limitations or federal maximum contaminant levels for water effluent
- National Ambient Air Quality Standards for vapor emissions.

The assumptions for the conceptual design are based on the following:

- Extraction well yield is obtained from step-drawdown aquifer tests.

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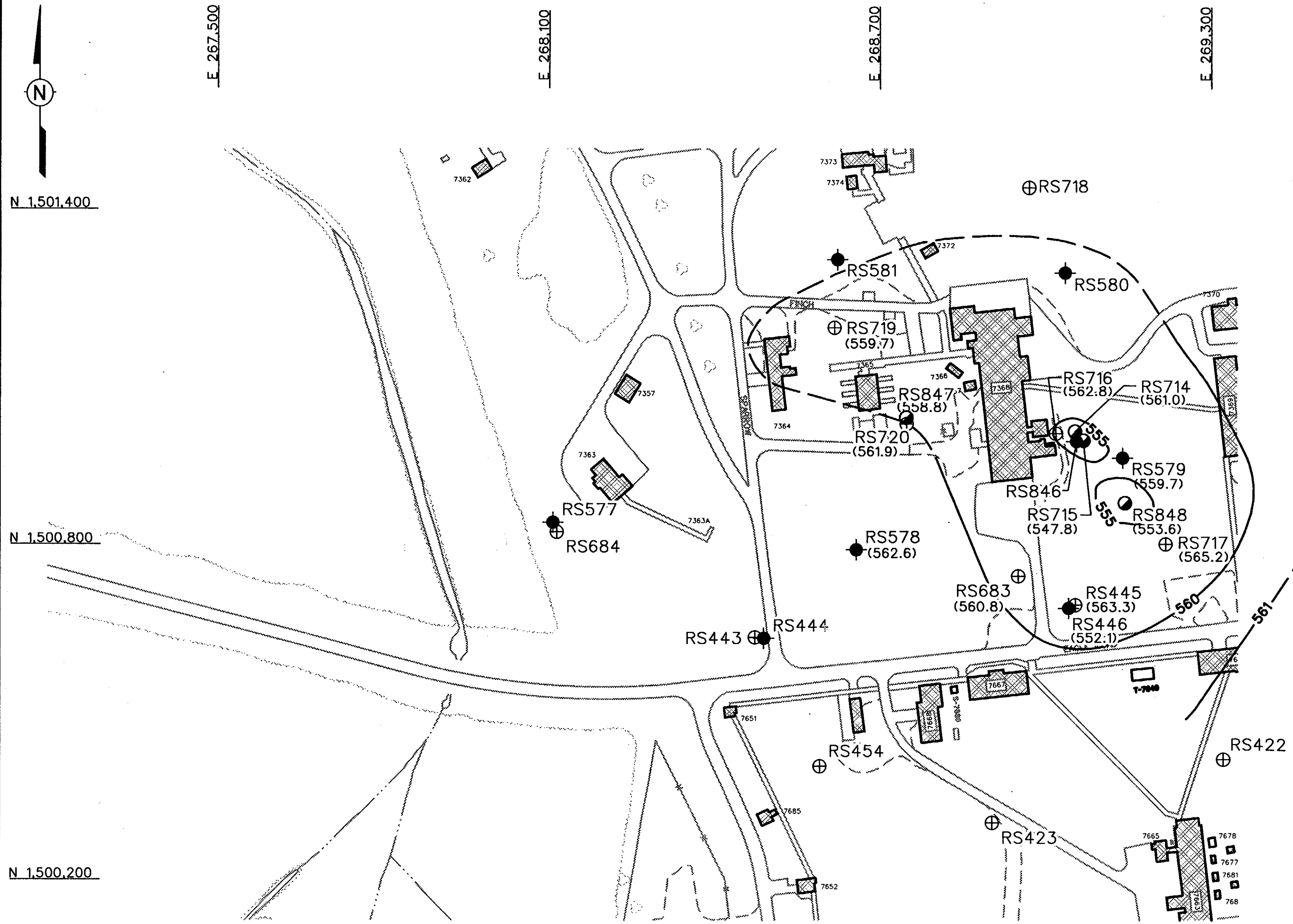

LEGEND

- UNIMPROVED ROADS AND PARKING
- PAVED ROADS AND PARKING
- TREES / TREELINE
- FENCE
- EXISTING REDIUUM MONITORING WELL
- EXISTING BEDROCK MONITORING WELL
- EXTRACTION WELL

FIGURE 1-3
RSA-95 ESTIMATED BEDROCK POTENTIOMETRIC SURFACE DUE TO PUMPING AT 3 WELLS

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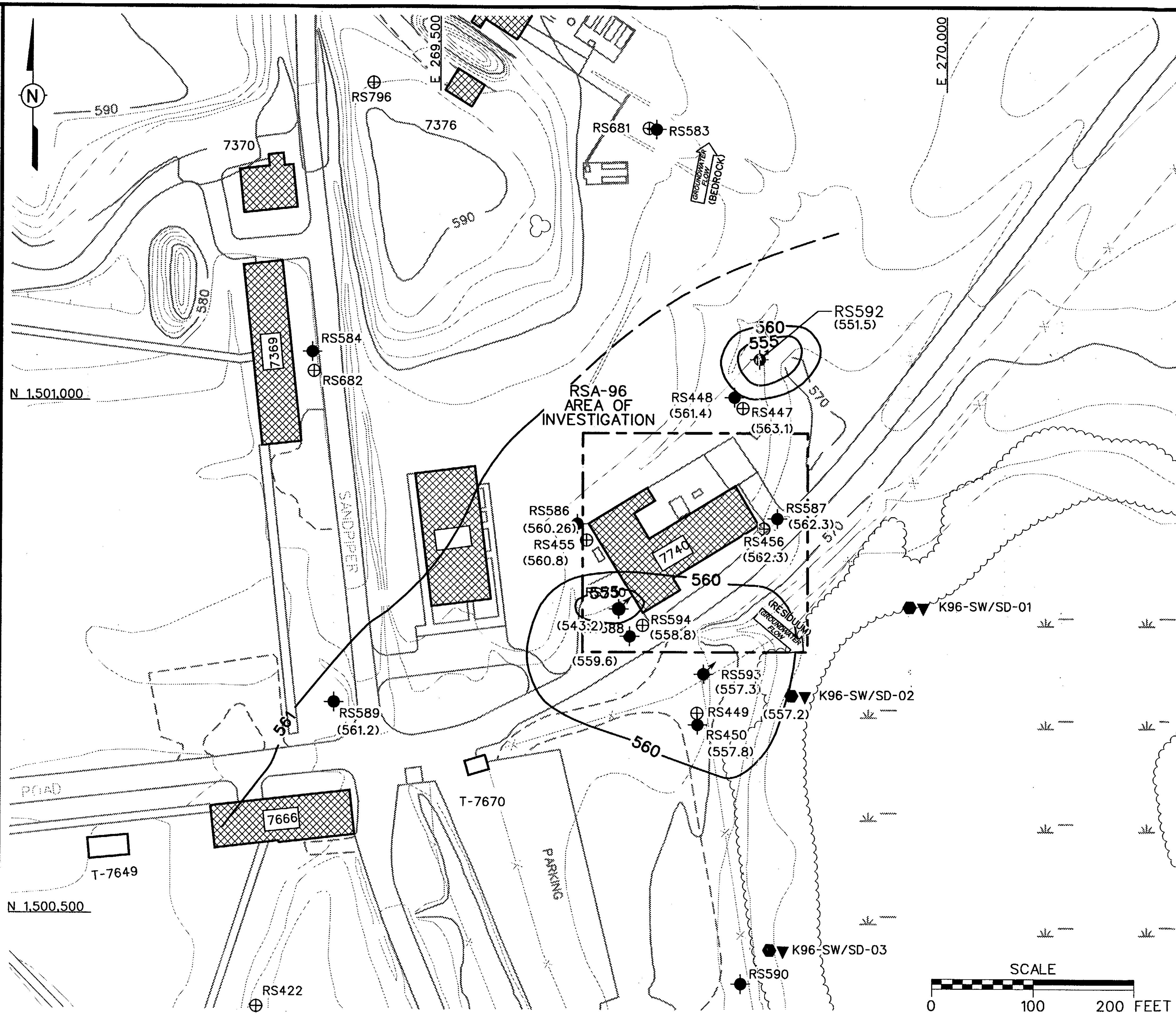

LEGEND

- UNIMPROVED ROADS AND PARKING
- PAVED ROADS AND PARKING
- TOPOGRAPHIC CONTOURS (FT-MSL)
- TREES / TREELINE
- FENCE
- RSA-96 AREA OF INVESTIGATION
- ANTICIPATED GROUNDWATER FLOW DIRECTION
- EXISTING RESIDUUM MONITORING WELL
- EXISTING BEDROCK MONITORING WELL
- SURFACE WATER/SEDIMENT SAMPLE PAIR LOCATION
- EXTRACTION WELL
- WETLANDS/MARSH

FIGURE 1-4

RSA-96 ESTIMATED BEDROCK POTENTIOMETRIC SURFACE DUE TO PUMPING AT 3 WELLS

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Table 2

Extraction Well Groundwater VOC Concentrations
Groundwater Extraction at RSA-95 and RSA-96
Redstone Arsenal, Madison County, Alabama

Compound	RSA-95			RSA-96		
	RS715	RS847	RS848	RS592	RS593	RS730
1,1 Dichlorethene	130	150	33	<400	<2000	<2000
1,1 Dichlorethane	0.46	<290	<100	<400	<2000	<2000
1,2 Dichloroethene	17	<290	9.6	43	310	500
Carbon Tetrachloride	5	<290	4.5	<400	<2000	<2000
Chloroform	36	<290	2.8	<400	<2000	<2000
1,1,1 Trichloroethane	2100	950	520	<400	960	360
1,1,2 Trichloroethene	1	<290	<100	<400	<2000	<2000
Tetrachloroethene	2	<290	<100	<400	<2000	<2000
Trichloroethene	8000	4800	2400	4100	31000	44000
Toluene	25	<290	<100	<400	<2000	<2000

Notes:

All concentrations are in micrograms per liter (µg/L).
Reported concentrations are from either last sample collected during pumping, or from the sample analyzed at the lowest dilution.
Compounds that were not detected are reported showing the detection limit.
Analyses by Method 8260A. Compounds that were not detected in any sample are not listed.

- Contaminant concentrations determined from extensive sampling of extraction wells during both; static and stressed aquifer conditions.

- Groundwater would be pumped from the wells to an equalization tank and then to the groundwater treatment system.

Discharge of the treatment stream through an outfall is proposed for final disposal of effluent water. The treatment stream discharge will meet the substantive requirements for a NPDES permitted outfall at Huntsville Spring Branch. Discharged limitations have not yet been established. Therefore, the NPDES discharge limitations are assumed to be the federal maximum contaminant levels.

Allowable levels of contaminants that can be released to the air are dependent on several factors including:

- Elevation of the release point above ground
- Terrain characteristics
- Distance to receptors.

Air stripper discharge concentrations and release rates (pounds per day [lb/day]) will not exceed the Alabama Department of Environmental Management PSD Air Quality Modeling Guidelines (1996). If the 1-hour air concentration for individual toxic chemicals are below 1/40th of the threshold limit value at the model emission exposure point, then the concentration or emission rate is below the maximum allowable air concentration.

1.3 Estimation of Contaminant Concentrations in Treatment Streams

Table 1 gives the selected extraction wells pumping rates. Table 2 gives VOC concentrations measured for each of the extraction wells at RSA-95 and RSA-96. Table 3 summarizes the expected chlorinated solvent recovery rates from groundwater in kilograms per day of dichloroethene, TCE, and trichloroethane (TCA). Table 4 provides the relative contribution of each well to the total TCE mass recovery if each well were pumped at the suggested rate. As can be seen from inspection of the data, recovery wells RS593, RS715, and RS730 contribute 37, 6, and 55 percent of the total TCE mass recovered, respectively. In addition, these wells would contribute 32, 41, and 12 percent of the total TCA recovered mass, respectively.

Table 3

Recovered Chlorinated Solvent Mass in Groundwater By Extraction Well
Groundwater Extraction at RSA-95 and RSA-96
Redstone Arsenal, Madison County, Alabama

Well	Discharge Rate (gpm)	Concentrations µg/L			Mass Recovery (Kg/day)		
		DCE	TCE	TCA	DCE	TCE	TCA
RSA-95							
RS715	60	147	8000	2100	0.04	2.41	0.63
RS847	30	150	4800	950	0.02	0.72	0.14
RS848	35	43	2400	520	0.01	0.42	0.09
				Total	0.07	3.55	0.87
RSA-96							
RS592	25	43	4100	ND	0.01	0.51	0.00
RS593	100	330	31000	960	0.17	15.53	0.48
RS730	100	500	44000	360	0.25	22.05	0.18
				Total	0.42	38.10	0.66

Concentrations from Table 2.

µg/L – Micrograms per liter.
kg/dy – Kilograms per day.
gpm – Gallons per minute.

Table 4

Contribution of Recovered Chlorinated Solvent Mass By Extraction Well
Groundwater Extraction at RSA-95 and RSA-96
Redstone Arsenal, Madison County, Alabama

Wells	Recovered Mass kg/day			Contribution to Total (%)		
	DCE	TCE	TCA	DCE	TCE	TCA
RS715	0.04	2.41	0.63	9%	6%	41%
RS847	0.02	0.72	0.14	5%	2%	9%
RS848	0.01	0.42	0.09	2%	1%	6%
RS592	0.01	0.51	0.00	1%	1%	0%
RS593	0.17	15.53	0.48	33%	37%	32%
RS730	0.25	22.05	0.18	51%	53%	12%
Total	0.50	41.65	1.53	100%	100%	100%
Contribution to Total by RS847, RS593 and RS730				88%	92%	53%
Contribution to Total by RS715, RS593 and RS730				93%	96%	85%

Mass recovery obtained from Table 3.

kg/day - Kilograms per day.

In order to estimate the concentrations of VOCs in the treatment stream, concentrations from the extraction wells were weighted by the discharge rate that each well contributed to the total flow. Table 5 gives the concentrations of contaminants in the treatment stream from each site, the concentrations in the combined stream and the discharge limitations for VOCs. Table 6 gives the concentrations in the treatment stream and combined stream if only the three most concentrated wells (RS730, RS593, and RS715) are used, and RS593 and RS730 are pumped at 125 and 150 gpm, respectively.

1.4 Technology and Process Screening and Selection of Remedial Technologies

1.4.1 Technology Screening

Preliminary evaluation of remedial technologies indicated there were limited options for groundwater mass removal in an interim action. The proposed IRA should also be considered for incorporation as part of the final design. The following technologies were evaluated for the criteria presented for the IRA.

- Slurry wall to contain contaminated groundwater
- In situ accelerated bioremediation
- Monitored natural attenuation
- Groundwater extraction and ex-situ treatment.

Installation of a slurry wall would alter the hydraulic gradient, impeding and redirecting plume migration, but will not reduce the mass of contaminants in groundwater. The effectiveness of a slurry wall in the OU-10 area is unknown and problematic.

In-situ bioremediation technologies comprise both active and passive methods. Active bioremediation consists primarily of either injection of a nutrient stream in water or injection of air. The main passive bioremediation technology is monitored natural attenuation. Chlorinated solvents such as TCE are recalcitrant to biodegradation, mainly being degraded as co-metabolites of more easily metabolized aromatic organic compounds. If in-situ bioremediation is to be effective, extensive bench scale and pilot scale testing is required, and the technology may not prove effective in reducing concentrations or in controlling contaminant plume migration.

Monitored natural attenuation may be a viable alternative for the final stages of remediation. But due to the very high concentrations of chlorinated compounds known at the degreaser release

Table 5

Contaminants and Concentrations in Degreaser Sites, Groundwater Treatment Stream, RSA-95 and RSA-96 Redstone Arsenal, Madison County, Alabama

Compound	Discharge Limitation[a]	RSA-95[b]	RSA-96[b]	Full Treatment Stream[b]
Discharge Rate (gpm)	-	125	225	350
1,1-Dichloroethene	7	109	<1	39
1,1-Dichloroethane	-	0	0	0
cis -1,2-Dichloroethene	70	8	374	243
Carbon tetrachloride	5	4	<1	1
Chloroform	80	20	0	7
1,1,1-Trichloroethane	200	1399	587	877
Tetrachloroethene	5	1	<1	0
Trichloroethene	5	5760	33789	23779

[a]Discharge limitations are federal MCLs.
[b]Concentrations are weighted means of the detectable concentration in the individual groundwater samples or individual treatment streams.
Contributions are weighted by the pumping rates for individual wells, as given in Table 3.
All values are in µg/L.
gpm - Gallons per minute.

Table 6

Contaminants and Concentrations in Groundwater Treatment Stream, RS715 at RSA-95 and RS593 and RS730 at RSA-96 Redstone Arsenal, Madison County, Alabama

Compound	Discharge Limitation[a]	RSA-95[b]	RSA-96[b]	Treatment Stream[b]
Discharge Rate (gpm)	-	70	275	345
1,1-Dichloroethene	7	130	<1	26
1,1-Dichloroethane	-	0	0	0
cis -1,2-Dichloroethene	70	17	751	602
Carbon tetrachloride	5	5	<1	1
Chloroform	80	36	0	7
1,1,1-Trichloroethane	200	2100	592	898
Tetrachloroethene	5	2	<1	0
Trichloroethene	5	8000	36909	31043

[a]Discharge limitations are the Federal MCLs.
[b]Concentrations are weighted means of the detectable concentration in the individual groundwater samples or individual treatment streams.
Contributions are weighted by the pumping rates for individual wells as given in Table 3.
All values are in µg/L.
gpm - gallons per minute.

sites, monitored natural attenuation will not provide the degree of contamination reduction or control of the contaminant plume migration required at RSA-95 and RSA-96.

Groundwater extraction will provide an immediate reduction in contaminant mass in the groundwater. In consideration of future site remedial actions, the groundwater extraction IRA system can be modified to control or prevent further migration of the most contaminated groundwater. Further, groundwater extraction and treatment is recognized as the presumptive remedy for contaminated groundwater. Based on these considerations, groundwater extraction and treatment was selected as the IRA for RSA-95 and RSA-96.

1.4.2 Process Options for Ex-Situ VOC Destruction

Existing treatment technologies evaluated for the IRA in reducing contaminant concentrations in recovered groundwater to meet discharge requirements are:

- Granular activated carbon (GAC)
- Air stripping
- Photolytic-chemical oxidation.

Other ex-situ technologies such as Fenton's chemistry and solvated electron reduction were considered during the technology screening. The photolytic-chemical oxidation process utilizes hydrogen peroxide and an iron catalyst similar to Fenton's chemistry and is not considered to be a separate technology. Solvated electron reduction technology uses a reactive metal (i.e., zero valent iron) to dechlorinate halogenated hydrocarbons. However, the reaction requires a relatively long contact time and therefore, is not considered to be suitable for an ex-situ treatment. Thus these technologies were not retained for evaluation.

Discharge of VOCs to the atmosphere is regulated in Alabama, therefore, the air emissions from the treatment system will require treatment. Use of vapor phase GAC (VGAC) will incur costs of disposal or regeneration. Catalytic thermal oxidation is an alternative to VGAC; however, the initial capital costs are very high and destruction of TCE and TCA by catalatic thermal oxidation will generate hydrochloric acid, necessitating the addition of an acid removal system.

The effectiveness of each of the retained treatment technologies in reducing the concentrations is dependent on the physical chemical properties of the compounds, the concentration of the compound in the treatment stream, and the flow rate of the treatment stream. Concentration reduction and process component usage for the retained technologies are given in Appendix B, OU-10 Treatment System Performance Calculations.

There are several configurations for handling the IRA groundwater extraction and treatment:

- Manifold extracted groundwater at each site together and treat separately at each site.
- Manifold extracted groundwater at each site and pump to a centralized treatment facility.
- Select wells exhibiting the highest concentrations of contaminants to be used for the IRA and build a centralized treatment system that can be expanded if additional wells are added at a later time.
- Installation of an effluent discharge line to Huntsville Spring Branch to meet the substantive NPDES requirements to surface water.

1.4.3 Process Descriptions

Carbon Adsorption. The carbon loading coefficient (***k***), expressed in milligrams of contaminant per gram of carbon describes how a compound adsorbs to GAC. If ***k*** is less than 4 milligrams per gram carbon, GAC will not be effective in treating groundwater, especially where concentrations or flow rates are high. Where ***k*** is 50 milligrams per gram carbon or greater, GAC would be effective in treating groundwater.

Activated carbon is effective in removing organic compounds until the adsorption sites are exhausted at which time breakthrough occurs, and the carbon is exhausted. The amount of carbon used on a daily basis is calculated as:

$$Usage\ rate\,(Lb\,/\,day) = \frac{[C]mg/L \bullet 3.78L/gal \bullet Qgpd \bullet 2.2lb\,/\,kg}{k \bullet 10^3 \qquad g\,/\,kg}$$

where:

[C] = contaminant concentration in milligrams per liter
Qgpd = flow rate in gallons per day.

Air Stripping. A compound's Henry's law coefficient (***H***) determines how well it will transfer from the liquid phase to the air phase during air stripping. Where ***H*** is less than 10 atm/mole-fraction air stripping will not be very effective in reducing concentrations, where ***H*** is greater than 200 atm/mole-fraction the compound will respond well to air stripping.

The transfer from the liquid to the vapor phase is dependent on the concentration of the contaminant, air and water temperature, and surface area of the water-air interface. A computer program supplied by Northeast Environmental Products was used to evaluate the removal efficiencies and concentrations of the contaminants in the effluent. The results are printed and included in Appendix B.

Photolytic Oxidation. Dissociation of compounds by irradiation of organic compounds with light of sufficient energy can disrupt chemical bonds of organic compounds. Where oxidizing agents (oxygen, hydrogen peroxide, or ozone) are present, oxidation of the disrupted molecule will destroy the contaminants. Ultraviolet (UV) light is used in energizing the contaminant molecules; either hydrogen peroxide or ozone is added to the water stream. In the oxidation process, because the OH radical in supplied at a constant rate, the contaminant concentration is the limiting factor in determining the reaction kinetics. Thus, the kinetics can be regarded to be first order, and the slope of the relationship between contaminant concentration and UV dose provides an easily comparable measure of treatment performance. The electrical energy required to generate enough UV to reduce the contaminant concentration by an order of magnitude (***E***) for 1,000 gallons of water has been empirically determined by a number of compounds (Solarchem Environmental Systems, 1994). Compounds that have ***E*** less than 10 respond well to photolytic oxidation.

The power requirements for reducing the concentration of a compound by an order of magnitude per 1,000 gallons is given by:

$$UV\,power\,(kW) = \frac{E \bullet 60 \bullet gpm \bullet \log([C_i]/[C_f])}{1000}$$

Where the power is fixed by the size of the treatment unit (180 kilowatts) and the flow rate (gpm) and initial concentration ($[C_i]$) are known, the final concentration can be computed as:

$$[C_f] = [C_i] \bullet 10^{-\frac{180kW \bullet 16.67}{E \bullet gpm}}$$

Based on the technology screening evaluation, a combination of treatment technologies will be considered. Treatment technologies that would remove the contaminants from the groundwater (liquid-phase pretreatment) to either reduce the contaminant load to the air stripper, or remove the organic compounds from the air stripper off-gas air stream (vapor-phase treatment) are:

- Air stripping and carbon and vapor-phase polishing
- UV light - ozone decomposition and air stripping
- UV oxidation and air stripping.

Options considered for vapor-phase treatment include:

- Vapor-phase carbon absorption
- Thermal catalyzed destruction.

1.4.4 Cost Summary Comparison

This evaluation of the treatment alternatives includes an analysis of implementability and efficiency of the treatment alternatives, and an analysis of the capital and operating costs. A 5-year period of operations and maintenance will be included in the cost evaluation to provide a uniform basis for evaluation of the long-term costs associated with each treatment technology. This report evaluates engineering alternatives, provides a cost comparison between the treatment configurations and options, and recommends a combined groundwater treatment facility. An evaluation of the cost associated with each treatment process is provided in Appendix C.

The cost estimates provided for each treatment alternative includes the capital costs of the equipment to treat the water and 5 years of operation and maintenance. Costs associated with installation of the extraction wells, transfer stations, or piping from each site to the centralized facility are not included in the cost estimate because these costs will be constant for all of the treatment alternatives. The material and construction costs were presented in the modification to delivery order number 0004, remedial design/remedial action long-term monitoring and compliance plan at OU-2, OU-5, OU-6b, OU-6c, and OU-10 (IT Corporation, 1998).

2.0 Evaluation of Treatment Alternatives

Groundwater will be pumped from each of the degreaser sites to a single treatment facility, where it will be processed to meet discharge limitations. This section describes the identified treatment alternatives for VOC destruction in the groundwater and gives a comparison of their respective capital and operating costs. Groundwater chemistry can affect the operation and effectiveness of water treatment systems. Thus, the evaluations presented in this document must be regarded as estimates for comparative evaluation only.

Groundwater is to be extracted and treated to remove VOCs as part of an IRA at two degreaser facilities, RSA-95 and RSA-96. Evaluation of groundwater contaminant concentrations at RSA-97 indicated groundwater extraction interim remedial measures are not required for this site. The goal of the IRA is TCE mass removal from the bedrock aquifer in order to prevent off-site migration of the contaminated groundwater and to reduce the relative risk at the degreaser sites hot spots. Groundwater extraction and treatment is a accepted presumptive remedy for VOC contamination. Because of the volume of treated effluent, it is recommended that treated effluent be discharged to surface water of sufficient capacity to meet substantive NPDES requirements.

A summary of the physical parameters and coefficients governing the response of the contaminants in groundwater at RSA-95 and RSA-96 to each of the treatment technologies is given in Table 7. Based on the suite of and concentrations of compounds present in the treatment stream, all contaminants in groundwater will be treated most effectively by air stripping, and most will be treated well by UV-oxidation. Maximum air concentrations allowed in the air stream are provided in Table 8. Most of the contaminants will be poorly adsorbed to carbon, however GAC may be a effective technology for polishing treated groundwater after a primary treatment by air stripping or UV-oxidation. Results of treatment stream, stripper removal, or chemical oxidation design calculation are included in Appendix B.

Three primary treatment alternatives are identified for evaluation:

- Liquid phase GAC
- Air stripping with GAC effluent polishing
- UV-oxidation and air stripping.

Using air stripping as the primary water treatment technology, the air emissions must be treated to meet the air emission levels. Two treatment alternatives that will be effective are:

Table 7

Physical Parameters and Coefficients and Evaluation of Technologies for Groundwater Treatment Alternatives RSA-95 and RSA-96 Redstone Arsenal, Madison County, Alabama

	MCL	Influent		Liquid Carbon Adsorption Coefficient	Henry's Law Coefficient	UV EE/O	Best Available Technology
		All Wells (μg/L)	Selected Wells (μg/L)	*k* (mg/g)	*h* (atm/MF)	(kWh/ 1k gal)	
1,1 Dichloroethene	7	39	26	1.5	1270	3	Air Stripping/UV Oxidation
1,1 Dichloroethane	-	0	0	0.15	326.2	30	Air Stripping
1,2 Dichlorethene	70	243	602	2	370	3	Air Stripping/UV Oxidation
Carbon Tertachloride	5	1	1	0.15	1643	30	Air Stripping/GAC
Chloroform	80	7	7	0.3	22520	30	Air Stripping
1,1,1 Trichlorethane	200	877	898	1	226.7	30	Air Stripping
Tetrachloroethene	5	1	1	4	1492	5	Air Stripping/GAC/UV Oxidation
Trichloroethene	5	23779	31043	28	648.2	3	Air Stripping/GAC/UV Oxidation

Notes:
All Wells - Full waste stream from RSA-95 and RSA-96.
Selected Wells - the three most contaminated wells; RS715, RS593 and RS730.
The value of k given for trichloroethene is for concentrations above 1000 μg/L. At concentrations below 1000 μg/L k is 7.
μg/L - Micrograms per liter.
mg/g - Miilligrams per gram.
atm/MF - Atmosphere per mole fraction.
kWh/kgal - Kilowatt hour per kilogallon.

Table 8

Allowable Levels of Organic Compounds in Treatment Stream Redstone Arsenal, Madison County, Alabama

Compound	Threshold Limit Value (mg/m^3)	Alabama Threshold Concentration (mg/m^3)	Maximum Allowable Influent Concentration (µg/L)				
			Discharge (gpm)				
			60	125	175	225	350
1,1 Dichloroethene	20.0	0.50	57	27	51	40	26
1,1 Dichloroethane	405.0	10.13	1149	546	1040	809	521
1,2 Dichloroethene	793.0	19.83	2250	1069	2037	1584	1019
Chloroform	48.7	1.22	138	66	125	97	63
Carbon Tetrachloride	32.0	0.80	91	43	82	64	41
1,1,1 Trichloroethane	1910	47.76	5421	2576	4907	3817	2456
Tetrachloroethene	170.0	4.25	482	229	437	340	218
Trichloroethene	269.0	6.72	763	363	691	537	346

Influent concentrations are calculated such that air stripper effluent complies to federal MCLs and the air discharge does not exceed 1/40th of the TLV in compliance to Alabama PSD Air Quality Modeling Guidelines (1996) for new sources of air toxics. The TWA was converted from ppm vol/vol to mg/M^3 using the molecular weight and molar volume of a vapor at 25°C

Influent Rate	Air Discharge Rate
60 and 125	900 cfm
175	1800 cfm
225 and 350	2400 cfm per unit

Air Discharge Limitation - 1/40th TLV

TLV - Time Weighted Average from 1998 Threshold Limit Values for Chemical Substances Physical Agents; American Conference of Government Industrial Hygienists.

µg/m^3 - Micrograms per cubic meter.
µg/L - Micrograms per liter.
gpm - Gallons per minute.

- Vapor-phase GAC
- UV-catalytic oxidation of air stripper discharge.

Bench-scale treatability studies on the effluent groundwater are crucial to determine the required peroxide dosage and the intensity of UV lights for the actual water. Iron precipitates may interfere with UV absorption by the target compounds, and removal of iron may be required before groundwater enters the UV/peroxide system to reduce solids coating on the UV lights.

2.1 Carbon Adsorption as the Primary Treatment Technology

Most of the contaminants will be poorly adsorbed to carbon, resulting in estimated poor performance in meeting effluent criteria. Carbon usage is calculated in Appendix B for each treatment stream. Total carbon usage ranges from 7,907 to 8,416 lb/day depending on which wells are pumped and how the influent streams are handled. Given the very high carbon usage rates and associated costs, GAC is not considered a viable primary treatment method.

2.2 Air Stripping as the Primary Treatment Technology

Air stripping will transfer the compounds to an air stream and discharge it to the atmosphere. The chlorinated solvent compounds in the treatment stream are considered toxic. The state of Alabama regulates the emissions of toxic compounds to the air as follows:

- If air emissions at the stack are less than 1/40th of the 1-hour time weighted average threshold limit value for the individual compound, then the concentrations are less than the maximum allowable concentration. Source: PSD Air Quality Modeling Guidelines (1996).

- New sources of toxic air emissions will not exceed 800 pounds per month (26.23 lb/day). Source: Alabama Code of Regulations 335-3-6.

Based on these air emission regulations, the maximum treatment stream concentration can be determined from which process air concentrations will exceed the time-weighted average or mass emission limit. The maximum allowable feed concentrations are given in Table 8. Comparison of the maximum allowable influent concentrations to the expected treatment stream concentrations (Table 5 and 6) to the values in Table 8 indicates that vapor phase TCE concentrations will exceed the maximum allowable concentrations in all cases. Therefore, vapor phase emissions control of the air stripper vapor discharge will be required if air stripping is used as the primary groundwater treatment technology. Figure 2-1 shows the system process flow diagram for these treatment alternatives (Alternatives 1 and 2 in Appendix C).

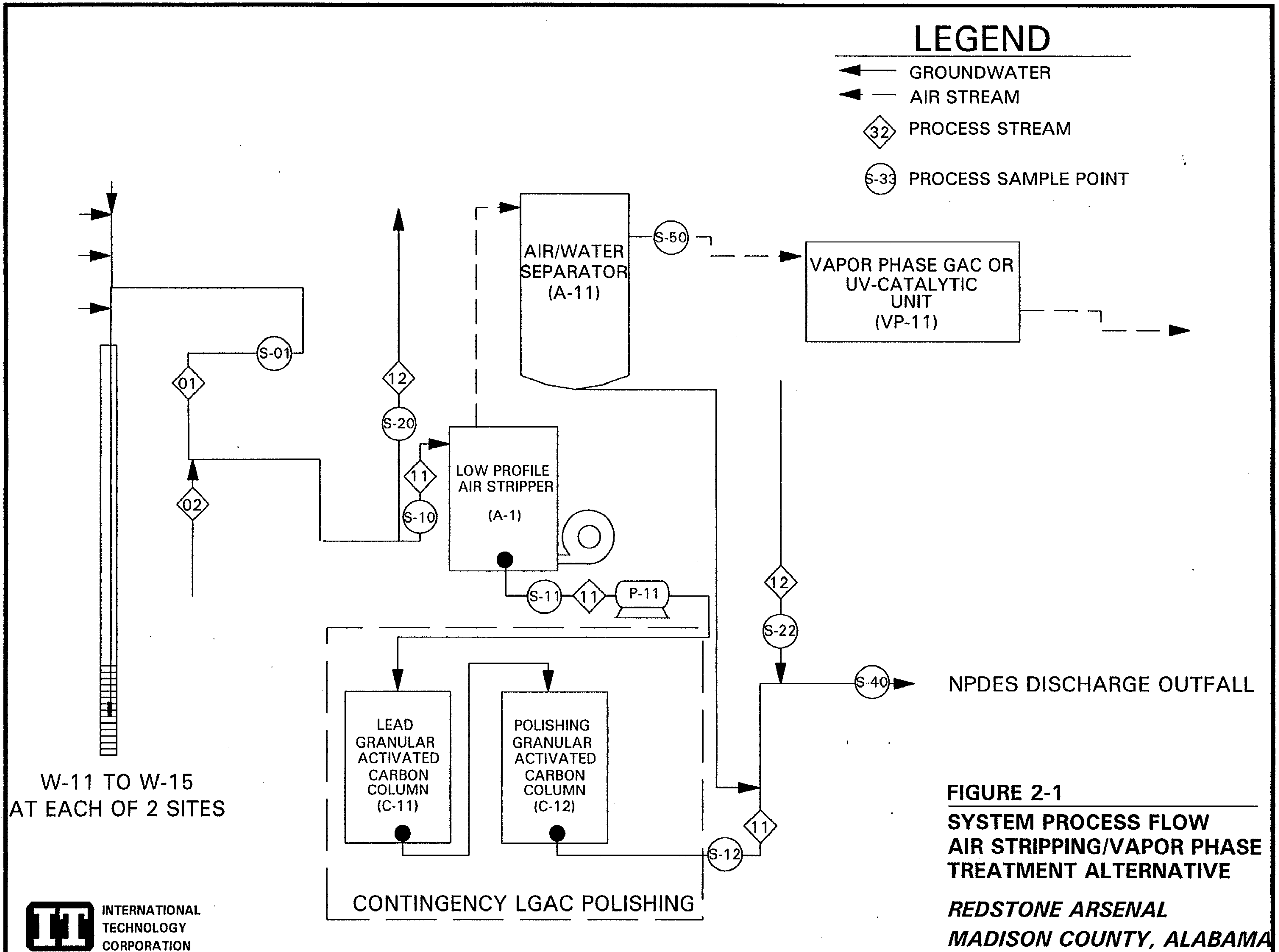

FIGURE 2-1

SYSTEM PROCESS FLOW AIR STRIPPING/VAPOR PHASE TREATMENT ALTERNATIVE

REDSTONE ARSENAL
MADISON COUNTY, ALABAMA

Table 9 provides a summary of the air stripping treatment configurations. Treatment of the total groundwater treatment stream from six recovery wells at RSA-95 and RSA-96 will require two air strippers, whether the streams are treated in one plant or two separate plants. If groundwater extraction is focused on the three wells exhibiting the highest levels of contamination (RS730, RS593, and RS715), then two treatment trains would be required if the sites are treated separately. Carbon consumption is similar whether the treatment streams are treated together or at the individuals sites.

Under all of the air stripping treatment configurations, LGAC and VGAC would be required to meet discharge limitations. Use of GAC will require continual and frequent monitoring to assure that contaminant breakthrough does not cause release of contaminants in excess of the discharge limitations. Use of LGAC would also require solids control in the process stream and possibly pH control to prevent precipitation of minerals in the process equipment and LGAC vessels. Isotherm tests should be performed to select the GAC most effective in absorption of the organic compounds in the liquid and vapor waste streams. Large canisters for liquid and vapor phase GAC up to 8,000 pounds are readily available. Using this size of canister for the VGAC, the canister would last about 16 days.

2.3 Chemical Oxidation and Polishing by Air Stripping

If the chemical load in the treatment stream can be reduced by destruction, then the pretreated waste stream may be treated by air stripping and the effluent and vapor stream will meet the discharge limitations with out requiring polishing by GAC. TCE is highly reactive when irradiated by UV light, especially in the presence of oxidizing agents such as hydrogen peroxide or ozone. Only TCE is present at concentrations at levels high enough that air concentrations would exceed the air discharge limitation. Therefore, treatment of the waste stream by chemical oxidation, followed by air stripping will be an effective means of meeting both the air and NPDES discharge limitations. Figure 2-2 shows the system process flow diagram for these treatment alternatives (Alternatives 3 and 4 in Appendix C).

Evaluation of the treatment train requirements of UV/oxidation pretreatment and polishing by air stripping is given in Table 9. As found for stripping, two treatment trains are required to treat the waste streams from the six recovery wells at RSA-95 and RSA-96.

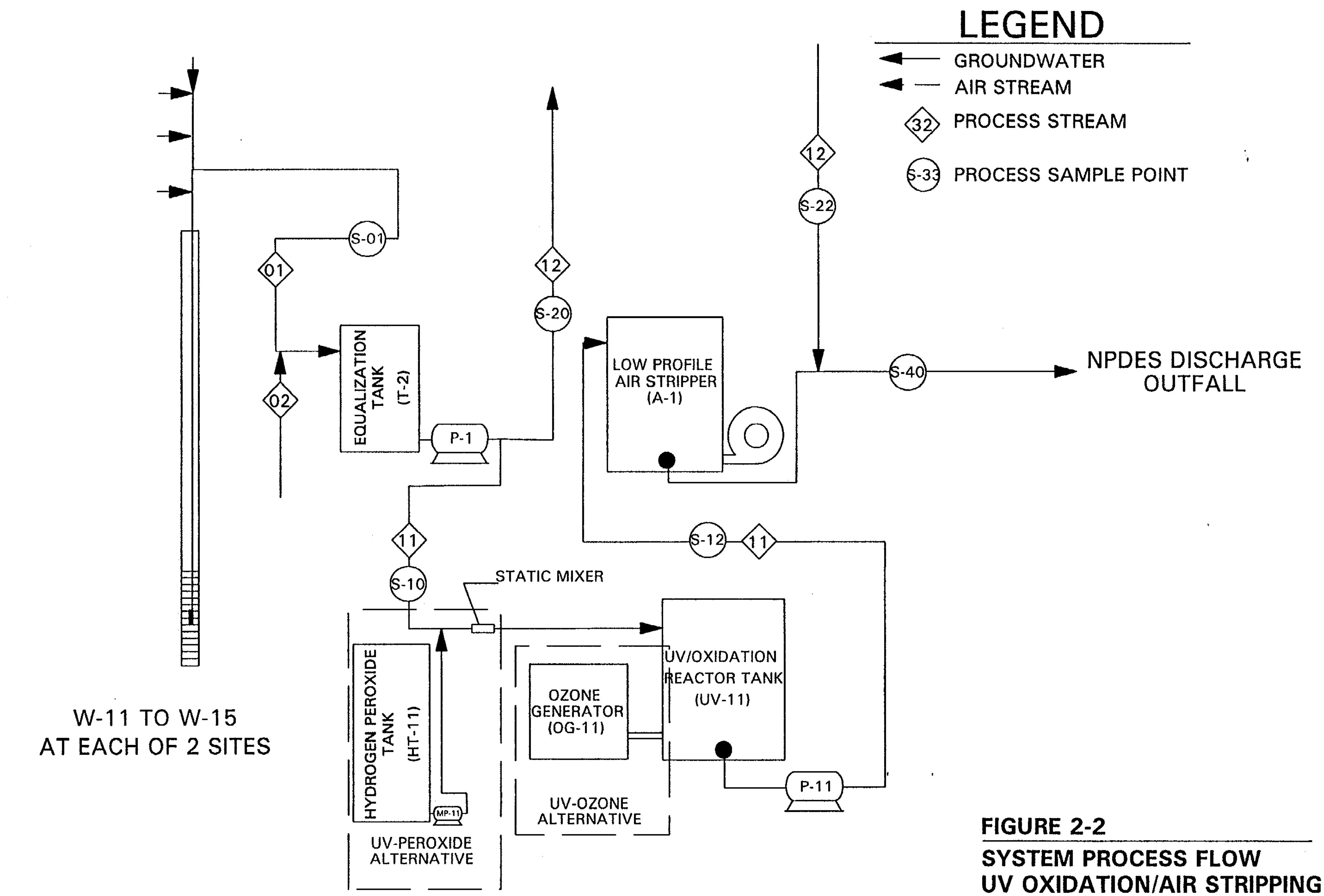

FIGURE 2-2
SYSTEM PROCESS FLOW
UV OXIDATION/AIR STRIPPING
TREATMENT ALTERNATIVE

REDSTONE ARSENAL
MADISION COUNTY, ALABAMA

INTERNATIONAL TECHNOLOGY CORPORATION

Table 9

Treatment System Evaluation Summary
Groundwater Extraction at RSA-95 and RSA-96
Redstone Arsenal, Madison County, Alabama

	Q (gpm)	Liquid Carbon Usage (Lb/dy)	Trays	Air Flow Rate (cfm)	Treatment Trains Required	Liquid GAC Usage (lb/dy)	Vapor GAC Usage (lb/dy)	Vapor VOC Emission (lb/dy)
		Section	Air Stripping with GAC - Section 2.2					
RSA-95	125	2792	3	1800	1	0	-	11
RSA-96	225	5624	4	2400	1	2	248	-
RS715	60	2283	3	900	1	-	-	9
RS593/RS730	200	7879	3	2400	1	1	333	-
RSA-95 and RSA-95	350	8416	4	2400	2	2	419	-
UV-Oxidation and Polishing by Air Stripping - Section 2.3								
RSA-95	125		2	900	1	-	-	0.3
RSA-96	225		2	1800	1	-	-	1
RS715	60		2	900	1	-	-	0.07
RS593/RS730	200		2	2400	1	-	-	1
RSA-95 and RSA-95	350		3	1800	2	-	-	1.5

UV - Oxidation uses a 180 Kw-hr unit as primary pretreatment.

Combined RSA-95/RSA-96 treatment stream is split into three parallel 250 gpm treatment trains. Carbon consumption is the total for all three treatment trains.

gpm - Gallons per minute.
lb/day – Pounds per day.
cfm – Cubic feet per minute.
GAC – Granular activated carbon.
Q – Discharge (gpm).
VOC – Volatile organic compound.

2.4 Summary

Technologies for use as a primary treatment of recovered groundwater containing TCE, TCA and their degradation products have been evaluated for use at RSA-95 and RSA-96. Based on evaluation of the pilot study data, consideration was given to the following four IRA scenarios:

- Treating groundwater from RSA-95 separately from groundwater from RSA-95
  - Pumping at all six wells
  - Pumping at RS715 at RSA-95 and RS593 and RS730 at RSA-96
- Combined discharge from both RSA-95 and RSA-96
  - Pumping at all six wells
  - Pumping at RS715 at RSA-95 and RS593 and RS730 RSA-96.

Air stripping is very efficient in removing both TCE and TCA from the waste stream and is the selected primary groundwater treatment. In addition, some LGAC polishing of the groundwater discharge may be required to meet NPDES requirements. Both technologies are available in standard stock components, have approximately 4 to 6 weeks lead times between ordering and delivery, and offer greater design flexibility. UV-oxidation is efficient in destroying TCE but TCA is recalcitrant to UV-oxidation. It was not selected due to the higher capital costs, the need for shelter of the unit, solids removal unit, and the long lead time for equipment manufacturing and delivery.

By using air stripping as the primary treatment, vapor phase treatment will be required. The vapor phase treatment considered here was VGAC. Because of the simplicity of an air stripping-VGAC treatment train, annual maintenance costs are minimized.

The extraction of groundwater at all six extraction wells at RSA-95 and RSA-96 would result in a waste stream requiring treatment of 350 gpm (Table 3).

Cost estimates for the IRA are being prepared separately. The cost summary comparison for the groundwater IRA are provided in Appendix C. The recommendation for the IRA remedial technology will be based on the cost comparison between the remedial alternatives. The technology screening is performed for the treatment facility, comparing remediation alternatives that combine several technologies that could possibly be implemented. Costs shown in Appendix C, indicate similar costs for Alternative 1 (air stripping and vapor phase carbon absorption) and Alternative 2 (air stripping and UV-catalytic oxidation air emission). Based on length of delivery for equipment and proven effectiveness of technology, Alternative 1 is technology screening is performed for the treatment facility, comparing remediation alternatives that combine several technologies that could possibly be implemented. Costs shown in Appendix C, indicate similar costs for Alternative 1 (air stripping and vapor phase carbon absorption) and Alternative 2 (air stripping and UV-catalytic oxidation air emission). Based on length of delivery for equipment and proven effectiveness of technology, Alternative 1 is recommended for the IRA remedial technology. Tables I-2 and I-3 present the preliminary cost estimates for Alternative 1.

The recommended remedial alternatives, based on the technical evaluations are:

- Pump at higher rates from selected wells where TCE concentrations are highest and allow the highest efficiencies for mass removal. Pump at lower rates from wells removed from the center of the known plume.

- Use air stripping to treat extracted groundwater and VGAC to treat the air stripper discharge.

- Centralize the treatment plant at a central location and build an effluent line of sufficient size to allow discharge of the IRA and additional effluent to the surface waters of Huntsville Spring Branch.

3.0 Conclusions and Recommendations

- Due to the complex nature of the combined treatment stream, and the high levels of TCE and 1,1,1-TCA in groundwater, a combination of treatment technologies will be required to reduce TCE mass in groundwater, meet the surface water discharge limitations effectively, and meet the Alabama Department of Environmental Management air emission limits.

- Air stripping is recommended as the primary groundwater treatment technology. VGAC is recommended for control of VOCs in the air stream and is the most cost-effective treatment technology.

- Pretreat (if required) extracted groundwater to remove iron and suspended solids.

- A groundwater recovery and treatment plant in excess of 350 gpm capacity should be designed and built in a centrally located area to allow collection and treatment of influent from RSA-95 and RSA-96.

- An effluent discharge line should be built to allow discharge of treated groundwater to surface waters of Huntsville Spring Branch. The line will allow discharge of the treated effluent to a surface water body that will allow compliance with substantive NPDES requirements. The capacity of the line should be designed to meet current and future OU-10 discharge requirements.

4.0 References

IT Corporation (IT), 1998, ***Total Environmental Restoration Contract (TERC) Redstone Arsenal***, February.

IT Corporation (IT), 1999a, ***Results of Well Performance and Pilot Groundwater Recovery Testing, RSA 95 and RSA 96, Operable Unit 10,*** June.

IT Corporation (IT), 1999b, ***Interim Remedial Action Work Plan, OU-10 Groundwater Recovery and Treatment System,*** June.

Solarchem Environmental Systems, 1994, ***The UV/Oxidation Handbook***.

U.S. Environmental Protection Agency (EPA), 1996, ***Final Guidance Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Groundwater at CERCLA Sites,*** CPA 540/R-96/023.

APPENDIX A

OU-10 PILOT TEST FLOW/CONCENTRATION DATA

Table A-1

Analytical Summary Table, Extraction Well RS592
Operable Unit 10 RSA-96
Redstone Arsenal, Madison County, Alabama

RS592 Date and Time	06/11/98	03/19/99	4/6 21:40	4/6 23:40	4/7 1:40	4/7 3:40	4/7 5:40	4/7 7:40	4/7 9:40	4/7 11:40
Sample Method	Standard	L. Flow	Pumping							
Acetone	2000 U	na	2500 U	2500 U	2000 U	2000 U	2500 U	2000 U	330 J,B	250 J,B
2-Butanone		na	1200 U	1200 U	1000 U	1000 U	1200 U	1000 U	1400 U	830 U
1,1 Dichlorethene	200 U	na	250 U	250 U	200 U	200 U	250 U	200 U	280 U	43 J,B
1,1 Dichloroethane	200 U	10 U	250 U	250 U	200 U	200 U	250 U	200 U	280 U	170 U
cis 1,2 Dichlorethene	82 J	263	140 J	55 J	53 J	55 J	52 J	52 J	280 U	170 U
Carbon Tetrachloride	200 U	na	250 U	250 U	200 U	200 U	250 U	200 U	280 U	170 U
Chloroform	200 U	na	250 U	250 U	200 U	200 U	250 U	200 U	280 U	170 U
Methylene Chloride	110 J	na	250 U	250 U	200 U	200 U	250 U	200 U	280 U	170 U
1,1,1 Trichloroethane	200 U	na	250 U	250 U	200 U	200 U	250 U	200 U	280 U	170 U
Tetrachloroethene	200 U	na	250 U	250 U	200 U	200 U	250 U	200 U	280 U	170 U
Trichloroethene	5100	95	2700	2500	2700	2900	2900	2900	2700	2800
1,1,2 trichloroethane	200 U	10 U	250 U	250 U	200 U	200 U	250 U	200 U	280 U	170 U
Toluene	200 U	na	250 U	250 U	200 U	200 U	250 U	200 U	280 U	170 U

Table A-1

Analytical Summary Table, Extraction Well RS592
Operable Unit 10 RSA-96
Redstone Arsenal, Madison County, Alabama

RS592 Date and Time Sample Method	4/7 17:15	4/7 19:15	4/7 21:15	4/7 23:15	4/8 1:15	4/8 1:15
	Pumping					Effluent
Acetone	400 J,B	420 J,B	4000 U	5000 U	440 J	7.5 J,B
2-Butanone	1800 U	1700 U	2000 U	2500 U	2000 U	25 U
1,1 Dichlorethene	360 U	330 U	400 U	500 U	400 U	5 U
1,1 Dichloroethane	360 U	330 U	400 U	500 U	400 U	5 U
cis 1,2 Dichlorethene	360 U	330 U	400 U	500 U	400 U	2 J
Carbon Tetrachloride	360 U	330 U	400 U	500 U	400 U	5 U
Chloroform	360 U	330 U	400 U	500 U	400 U	2.3 J
Methylene Chloride	360 U	330 U	400 U	500 U	400 U	5 U
1,1,1 Trichloroethane	360 U	330 U	400 U	500 U	400 U	5 U
Tetrachloroethene	360 U	330 U	400 U	500 U	400 U	5 U
Trichloroethene	3400	3900	4100	4600	4100	120
1,1,2 trichloroethane	360 U	330 U	400 U	500 U	400 U	5 U
Toluene	360 U	330 U	400 U	500 U	400 U	5 U

Notes:
U - Not detected at indicated detection limit.
na - Not analyzed.
J - Estimated concentrations below the detection limit.
B - Compound also detected in method blank.
All concentrations are in micrograms per liter (µg/L).

Table A-2

Analytical Summary Table, Extraction Well RS593
Operable Unit 10 RSA-96
Redstone Arsenal, Madison County, Alabama

RS 593 Date and Time	06/28/96	03/19/99	4/5 15:00	4/5 17:00	4/5 19:00	4/5 21:00	4/5 23:00
Sample Method	Standard	L. Flow	Pumping				
2-Butanone	4000 U		7400 U	5000 U	7400 U	7400 U	7400 U
1,1 Dichlorethene	2000 U	na	1500 U	1000 U	1500 U	1500 U	1500 U
1,1 Dichloroethane	2000 U	10 U	1500 U	1000 U	1500 U	1500 U	1500 U
cis 1,2 Dichlorethene	2000 U	287	1500 U	230 J	1500 U	1500 U	1500 U
Carbon Tetrachloride	2000 U	na	1500 U	1000 U	1500 U	1500 U	1500 U
Chloroform	2000 U	na	1500 U	1000 U	1500 U	1500 U	1500 U
Methylene Chloride	2000 U	na	1500 U	1000 U	1300 J,B	1400 J,B	1300 J,B
1,1,1 Trichloroethane	2000 U	na	1500 U	1000 U	1500 U	1500 U	1500 U
Tetrachloroethene	2000 U	na	1500 U	1000 U	1500 U	1500 U	1500 U
Trichloroethene	52000	63102	57000	37000	35000	31000	31000
1,1,2 trichloroethane	2000 U	10 U	1500 U	1000 U	1500 U	1500 U	1500 U
Toluene	2000 U	na	1500 U	1000 U	1500 U	1500 U	1500 U

Table A-2

Analytical Summary Table, Extraction Well RS593
Operable Unit 10 RSA-96
Redstone Arsenal, Madison County, Alabama

RS 593 Date and Time	4/6 1:00	4/6 3:00	4/6 6:00	4/6 9:00	4/6 11:00	4/6 13:00	4/6 15:00	4/6 15:00
Sample Method	Pumping							Effluent
2-Butanone	7400 U	7400 U	5000 U	8300 U	10000 U	12000 U	10000 U	250 U
1,1 Dichlorethene	1500 U	1500 U	1000 U	1700 U	2000 U	2500 U	2000 U	50 U
1,1 Dichloroethane	1500 U	1500 U	1000 U	1700 U	2000 U	2500 U	2000 U	50 U
cis 1,2 Dichlorethene	1500 U	1500 U	310 J	1700 U	2000 U	2500 U	2000 U	17 J
Carbon Tetrachloride	1500 U	1500 U	1000 U	1700 U	2000 U	2500 U	2000 U	50 U
Chloroform	1500 U	1500 U	1000 U	1700 U	2000 U	2500 U	2000 U	50 U
Methylene Chloride	1400 J,B	1400 J,B	720 J,B	1700 U	2000 U	2500 U	2000 U	50 U
1,1,1 Trichloroethane	1500 U	1500 U	1000 U	1700 U	2000 U	2500 U	960 J	23 J
Tetrachloroethene	1500 U	1500 U	1000 U	1700 U	2000 U	2500 U	2000 U	50 U
Trichloroethene	34000	31000	29000	22000	23000	25000	31000	720
1,1,2 trichloroethane	1500 U	1500 U	1000 U	1700 U	2000 U	2500 U	2000 U	50 U
Toluene	1500 U	1500 U	1000 U	1700 U	2000 U	2500 U	2000 U	50 U

Notes:
U - Not detected at indicated detection limit.
na - Not analyzed.
J - Estimated concentrations below the detection limit.
B - Compound also detected in method blank.
All concentrations are in micrograms per liter (µg/L).

Table A-3

Analytical Summary Table, Extraction Well RS730
Operable Unit 10, RSA-96
Redstone Arsenal, Madison County, Alabama

(Page 1 of 2)

RS 730 Date and Time	02/25/99	3/17/99	3/31 15:30	3/31 17:30	3/31 19:30	3/31 21:30	3/31 23:03	4/1 1:30
Sample Method	Low Flow	Pumping	Pumping					
2-Butanone	10000 U	10000 U	10000 U	10000 U	10000 U	10000 U	10000 U	10000 U
1,1 Dichlorethene	2000 U	270 J	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U
1,1 Dichloroethane	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U
cis 1,2 Dichlorethene	2000 U	1100 J	530 J	1100 J	1000 J	1200 J	1000 J	800 J
Carbon Tetrachloride	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U
Chloroform	2000 U	320 J	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U
Methylene Chloride	2000 U	1400 J	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U
1,1,1 Trichloroethane	2000 U	440 J	310 J	2000 U	2000 U	360 J	2000 U	2000 U
Tetrachloroethene	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U
Trichloroethene	59000	68000	37000	51000	57000	65000	62000	61000
1,1,2 trichloroethane	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U
Toluene	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U
Bromodichloromethane	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U
Dibromochloromethane	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U

Table A-3

Analytical Summary Table, Extraction Well RS730
Operable Unit 10, RSA-96
Redstone Arsenal, Madison County, Alabama

(Page 2 of 2)

RS 730 Date and Time	4/1 3:30	4/1 5:30	4/1 7:30	4/1 9:30	4/1 11:30	4/1 13:30	4/1 15:30	4/1 15:30
Sample Method	Pumping							EFFLUENT
2-Butanone	10000 U	10000 U	10000 U	10000 U	10000 U	10000 U	10000 U	250 U
1,1 Dichlorethene	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	50 U
1,1 Dichloroethane	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	50 U
cis 1,2 Dichlorethene	710 J	660 J	610 J	590 J	620 J	520 J	500 J	19 J
Carbon Tetrachloride	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	50 U
Chloroform	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	50 U
Methylene Chloride	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	50 U
1,1,1 Trichloroethane	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	50 U
Tetrachloroethene	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	50 U
Trichloroethene	53000	52000	49000	44000	45000	43000	44000	870
1,1,2 trichloroethane	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	50 U
Toluene	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	50 U
Bromodichloromethane	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	50 U
Dibromochloromethane	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	2000 U	50 U

Notes:
U - Not detected at indicated detection limit.
na - Not analyzed.
J - Estimated concentrations below the detection limit.
B - Compound also detected in method blank.
All concentrations are in micrograms per liter (µg/L).

Table A-4

Analytical Summary Table, Extraction Well RS715
Operable Unit 10, RSA-95
Redstone Arsenal, Madison County, Alabama

(Page 1 of 2)

RS 715 Date and Time	02/24/99	03/12/99	3/23 9:00	3/23 11:00	3/23 13:00	3/23 15:00	3/23 17:00	3/23 19:00
Sample Method	LOW FLOW	Pumping	Pumping	Pumping				
2-Butanone	1000 U	2000 U	620 U	1000 U	830 U	5 U	830 U	1800 U
1,1 Dichlorethene	200 U	160 J	J J	110 J	80 J	80 J,D	77 J	89 J
1,1 Dichloroethane	200 U	400 U	120 U	200 U	170 U	0.46 J	170 U	200 U
cis 1,2 Dichloroethene	200 U	400 U	120 U	200 U	170 U	17	170 U	38 J
Carbon Tetrachloride	200 U	400 U	120 U	200 U	170 U	5.2	170 U	200 U
Chloroform	200 U	400 U	30 J	47 J	31 J	3.1	170 J	200 U
Methylene Chloride	200 U	400 U	120 B	230 B	170 B	1.5 B	180 B	210 B
1,1,1 Trichloroethane	2300	2700	640	2500	1700	1200 D	1500	1800
Tetrachloroethene	200 U	400 U	120 U	200 U	170 U	1.6	170 U	200 U
Trichloroethene	6200	8700	3400	7800	5800	5400 D	5300	6100 U
1,1,2 trichloroethane	200 U	400 U	120 U	200 U	170 U	1.1	170 U	200 U
Toluene	200 U	400 U	120 U	200 U	170 U	0.35 J	170 U	200 U
Benzene	200 U	400 U	13 J,B	200 U	170 U	1 U	170 U	200 U

Table A-4

Analytical Summary Table, Extraction Well RS715
Operable Unit 10, RSA-95
Redstone Arsenal, Madison County, Alabama

(Page 2 of 2)

RS 715 Date and Time	3/23 21:00	3/23 23:00	3/24 1:00	3/24 3:00	3/24 5:00	3/24 7:00	3/24 9:00
Sample Method	Pumping						
2-Butanone	1000 U	1000 U	1000 U	1000 U	1000 U	1000 U	1000 U
1,1 Dichlorethene	110 J	81 J	94 J	120 J	120 J	130 J	130 J
1,1 Dichloroethane	200 U	200 U	200 U	200 U	200 U	200 U	200 U
cis 1,2 Dichloroethene	200 U	200 U	200 U	200 U	200 U	200 U	200 U
Carbon Tetrachloride	200 U	200 U	200 U	200 U	200 U	200 U	200 U
Chloroform	44 J	35 J,B	200 U	32 J,B	200 U	31 J,B	36 J,B
Methylene Chloride	240 B	1000 B	530 B	460 B	500 B	520 B	470 B
1,1,1 Trichloroethane	2100	1400	1500	2100	2000	2100	2100
Tetrachloroethene	200 U	200 U	200 U	200 U	200 U	200 U	200 U
Trichloroethene	6600	5300	5900	7300 U	7300	7700	8000
1,1,2 trichloroethane	200 U	200 U	200 U	200 U	200 U	200 U	200 U
Toluene	200 U	200 U	29 J	26 J	26 J	200 U	25 J
Benzene	200 U	200 U	200 U	200 U	200 U	200 U	200 U

Notes:
U - Not detected at indicated detection limit.
na - Not analyzed.
J - Estimated concentrations below the detection limit.
B - Compound also detected in method blank.
All concentrations are in micrograms per liter (µg/L).

Table A-5

Analytical Summary Table, Extraction Well RS847
Operable Unit 10, RSA-95
Redstone Arsenal, Madison County, Alabama

RS847 Date and Time	02/25/99	03/16/99	3/29 22:00	3/30 0:00	3/30 2:00	3/30 4:00	3/30 6:00	3/30 8:00	3/30 10:00	3/30 12:00	3/30 14:00
Sample Method	Low flow	Pumping	Pumping								Pumping
Bromomethane	50 U	50 U	250 U	250 U	250 U	250 U	590 U	33 J,B	590 U	30 J,B	590 U
2-Butanone	250 U	830 U	440 J	620 U	620 U	620 U	1500 U	1000 U	1500 U	1000 U	1500 U
1,1 Dichlorethene	50 U	170 U	75 J	86 J	95 J	87 J	55 J	90 J	64 J	70 J,B	84 J
1,1 Dichloroethane	50 U	170 U	120 U	120 U	120 U	120 U	290 U	200 U	290 U	200 U	290 U
cis 1,2 Dichlorethene	50 U	170 U	120 U	120 U	120 U	120 U	290 U	200 U	290 U	200 U	290 U
Carbon Tetrachloride	50 U	170 U	120 U	120 U	120 U	120 U	290 U	200 U	290 U	200 U	290 U
Chloroform	50 U	170 U	120 U	120 U	120 U	120 U	290 U	200 U	290 U	200 U	290 U
Methylene Chloride	50 U	170 U	120 U	120 U	120 U	120 U	290 U	200 U	290 U	200 U	290 U
1,1,1 Trichloroethane	50 U	240	420	460 J	480	440	390	370	440	380	570
Tetrachloroethene	50 U	170 U	120 U	120 U	120 U	120 U	290 U	200 U	290 U	200 U	290 U
Trichloroethene	1300	3800	4100 D	3900 D	4900 D	5000 D	4000	6900	4100	3200	4100
1,1,2 trichloroethane	50 U	170 U	120 U	120 U	120 U	120 U	290 U	200 U	290 U	200 U	290 U
Toluene	50 U	170 U	120 U	120 U	120 U	120 U	290 U	200 U	290 U	200 U	290 U

Table A-5

Analytical Summary Table, Extraction Well RS847
Operable Unit 10, RSA-95
Redstone Arsenal, Madison County, Alabama

RS847 Date and Time	3/30 16:00	3/30 18:00	3/30 20:00	3/30 22:00	3/30 22:00
Sample Method	Pumping		Pumping		EFFLUENT
Bromomethane	400 U	590 U	400 U	590 U	10 U
2-Butanone	100 U	1500 U	1000 U	1500 U	25 U
1,1 Dichlorethene	110 J	120 J	140 J	150 J	1.4 J
1,1 Dichloroethane	200 U	290 U	200 U	290 U	5 U
cis 1,2 Dichlorethene	200 U	290 U	200 U	290 U	5 U
Carbon Tetrachloride	200 U	290 U	200 U	290 U	5 U
Chloroform	200 U	290 U	200 U	290 U	5 U
Methylene Chloride	200 U	290 U	950	290 U	5 U
1,1,1 Trichloroethane	640	760	520	950	15
Tetrachloroethene	200 U	290 U	200 U	290 U	5 U
Trichloroethene	4200	4400	4200	4800	96
1,1,2 trichloroethane	200 U	290 U	200 U	290 U	5 U
Toluene	200 U	290 U	20 J	290 U	5 U

Notes:
U - Not detected at indicated detection limit.
na - Not analyzed.
J - Estimated concentrations below the detection limit.
B - Compound also detected in method blank.
All concentrations are in micrograms per liter (μg/L).

Table A-6

Analytical Summary Table, Extraction Well RS848
Operable Unit 10, RSA-95
Redstone Arsenal, Madison County, Alabama

RS848 Date and Time	02/23/99	03/11/99	3/25 13:00	3/25 15:00	3/25 17:00	3/25 19:00	3/25 21:00	3/25 23:00
Sample Method	Low Flow	Pumping	Pumping					
2-Butanone	5 U	310 U	100 U	250 U	250 U	250 U	250 U	100 U
1,1 Dichloroethene	1 U	20 J	6.6 J	7.7 J	11 J	15 J	17 J	20
1,1 Dichloroethane	1 U	62 U	20 U	50 U	50 U	50 U	50 U	20 U
cis 1,2 Dichlorethene	1 U	62 U	6.2 J	50 U	50 U	50 U	50 U	9.6 J
Carbon Tetrachloride	1 U	62 U	20 U	50 U	50 U	50 U	50 U	4.4 J
Chloroform	1 U	12 J,B	20 U	50 U	50 U	50 U	50 U	20 U
Methylene Chloride	1 U	52 J,B	20 U	50 U	50 U	50 U	50 U	20 U
1,1,1 Trichloroethane	0.55 J	240	26	50	98	180	220	250
Tetrachloroethene	1 U	62 U	20 U	50 U	50 U	50 U	50 U	20 U
Trichloroethene	4.2 J	1600	470	650	810	1100	1300	1400 D
1,1,2 trichloroethane	1 U	62 U	20 U	50 U	50 U	50 U	50 U	20 U
Toluene	1 U	62 U	20 U	50 U	50 U	50 U	50 U	20 U

Table A-6

Analytical Summary Table, Extraction Well RS848
Operable Unit 10, RSA-95
Redstone Arsenal, Madison County, Alabama

RS848 Date and Time	3/26 1:00	3/26 3:00	3/26 5:00	3/26 7:00	3/26 9:00	3/26 11:00	3/26 13:00
Sample Method	Pumping						
2-Butanone	100 U	100 U	250 U	500 U	500 U	500 U	500 U
1,1 Dichloroethene	23	25	26 J	28 J	28 J	31 J	33 J
1,1 Dichloroethane	20 U	20 U	50 U	100 U	100 U	100 U	100 U
cis 1,2 Dichlorethene	9.6 J	10 J	11 J	100 U	100 U	100 U	100 U
Carbon Tetrachloride	4.5 J	4.5 J	50 U	100 U	100 U	100 U	100 U
Chloroform	2.8 J	20 U	50 U	100 U	100 U	100 U	100 U
Methylene Chloride	20 U	20 U	50 U	100 U	100 U	100 U	100 U
1,1,1 Trichloroethane	290	330	380	410	450	510	520
Tetrachloroethene	20 U	20 U	50 U	100 U	100 U	100 U	100 U
Trichloroethene	1500 D	1700 D	1800	2000	2100	2300	2400
1,1,2 trichloroethane	20 U	20 U	50 U	100 U	100 U	100 U	100 U
Toluene	20 U	20 U	50 U	100 U	100 U	100 U	100 U

Notes:
U - Not detected at indicated detection limit.
na - Not analyzed.
J - Estimated concentrations below the detection limit.
B - Compound also detected in method blank.
All concentrations are in micrograms per liter (μg/L).

APPENDIX B

OU-10 TREATMENT SYSTEM PERFORMANCE CALCULATIONS

Table B-1

Single Site Treatment Facility Evaluation Results for RSA-95
Redstone Arsenal, Madison County, Alabama

RSA 95	Expected Concentration in Treatment Stream µg/L	Liquid Carbon Usage (lb/dy)	Primary Air Stripping Treatment Effluent µg/L	Carbon Usage Liquid Polishing (lb/dy)	Air Stream (mg/m^3)	Vapor Phase Release (lb/dy)	Vapor Phase Carbon Usage (lb/dy)	UV OX [C] effluent µg/L	Air Strip [C] effluent µg/L	Air Stream (mg/m^3)	Vapor Phase Release (lb/dy)
1,1 Dichlorethene	109	109	0	0	1.012	0.163	0.4	0.0	0	0.0	0.0
1,1 Dichloroethane	0.2	2.20	0	0	0	0	0.0033	0.03	0	0.0	0.0
1,2 Dichlorethene	8	6	0	0	0.08	0.01	0.03	0	0	0.0	0.0
Carbon Tetrachloride	4	12	0	0	0.03	0.01	0.05	1	0	0.0	0.0
Chloroform	20	101	0	0	0.2	0.0	0.60	3	0	0.02	0.0
1,1,1 Trichlorethane	1399	2094	0	0	13	2	7	222	4	2	0.3
Tetrachloroethene	1	0.23	0	0	0	0	0.003	0	0	0.0	0.0
Trichlorethene	5760	468	1	0	53	9	23	0	0	0.0	0.0
	Total (lb/dy)	2792		0		11	31				0.3

Notes:
Treatment stream concentrations are weighted averages, weighted by the well's contribution to the total discharge for the site.
Cumulative discharge rate from all wells = 125
Carbon loading for TCE concentrations above 1000 µg/L is 28 mg/g carbon
Primary air stripping uses a 3 tray 1800 cfm air stripping unit (Model 31231).
UV-Oxidation-Air Stripper treatment unit uses one 180kW UV/Ox System and one 2-tray 900 cfm (Model 3621) air stripper.

ShallowTray
low profile air strippers

System Performance Estimate

Client and Proposal Information:

Redstone Arsenal OU-10
Air Stripping Primary Treatment
RSA-95 Single Site

Model Chosen:	31200
Water Flow Rate:	125.0 gpm
Air Flow Rate:	1800 cfm
Water Temp:	56.0 F
Air Temp:	60.0 F
A/W Ratio:	107.7
Safety Factor:	5%

Contaminant	**Untreated Influent** Effluent Target	**Model 31211 Effluent** **Water** Air(lbs/hr) % removal	**Model 31221 Effluent** **Water** Air(lbs/hr) % removal	**Model 31231 Effluent** **Water** Air(lbs/hr) % removal
1,1,1-Trichloroethane	**1399 ppb** 200 ppb	**65 ppb** 0.083412 95.4221%	**3 ppb** 0.087288 99.7904%	**<1 ppb** 0.087468 99.9904%
1,1-Dichloroethylene	**109 ppb** 7 ppb	**3 ppb** 0.006628 97.7456%	**<1 ppb** 0.006812 99.9492%	**<1 ppb** 0.006815 99.9989%
c-1,2-Dichloroethylene	**8 ppb** 1 ppb	**2 ppb** 0.000375 85.3185%	**<1 ppb** 0.000489 97.8445%	**<1 ppb** 0.000499 99.6835%
Carbon Tetrachloride	**4 ppb** 1 ppb	**<1 ppb** 0.000246 98.2622%	**<1 ppb** 0.000250 99.9698%	**<1 ppb** 0.000250 99.9995%
Chloroform	**20 ppb** 8 ppb	**2 ppb** 0.001125 92.5368%	**<1 ppb** 0.001244 99.4430%	**<1 ppb** 0.001250 99.9584%
Tetrachloroethylene	**1 ppb** 0 ppb	**<1 ppb** 0.000061 97.4083%	**<1 ppb** 0.000062 99.9328%	**<1 ppb** 0.000063 99.9983%
Trichloroethylene	**5760 ppb** 5 ppb	**210 ppb** 0.347028 96.3598%	**8 ppb** 0.359658 99.8675%	**1 ppb** 0.360096 99.9952%

This report has been generated by ShallowTray Modeler software version 2.1W. This software is designed to assist a skilled operator in predicting the performance of a ShallowTray air stripping system. North East Environmental Products, Inc. is not responsible for incidental or consequential damages resulting from the improper operation of either the software or the air stripping equipment.
Report generated: 7/9/1999

ShallowTray
low profile air strippers

System Performance Estimate

Client and Proposal Information:

Redstone Arsenal OU-10
UV/OX Primary Treatment
RSA-95 SINGLE SITE

Model Chosen: 3600
Water Flow Rate: 125.0 gpm
Air Flow Rate: 900 cfm
Water Temp: 56.0 F
Air Temp: 60.0 F
A/W Ratio: 53.9
Safety Factor: 5%

Contaminant	Untreated Influent / Effluent Target	Model 3611 Effluent Water / Air(lbs/hr) / % removal	Model 3621 Effluent Water / Air(lbs/hr) / % removal	Model 3631 Effluent Water / Air(lbs/hr) / % removal	Model 3641 Effluent Water / Air(lbs/hr) / % removal
1,1,1-Trichloroethane	**222 ppb** 200 ppb	**29 ppb** 0.012068 87.2044%	**4 ppb** 0.013631 98.3627%	**1 ppb** 0.013819 99.7905%	**<1 ppb** 0.013877 99.9732%
1,1-Dichloroethylene	**1 ppb** 7 ppb	**<1 ppb** 0.000058 92.2423%	**<1 ppb** 0.000062 99.3982%	**<1 ppb** 0.000062 99.9533%	**<1 ppb** 0.000063 99.9964%
c-1,2-Dichloroethylene	**1 ppb** 1 ppb	**1 ppb** <.000001 65.6352%	**<1 ppb** 0.000055 88.1906%	**<1 ppb** 0.000060 95.9417%	**<1 ppb** 0.000062 98.6054%
Carbon Tetrachloride	**1 ppb** 1 ppb	**<1 ppb** 0.000054 86.5056%	**<1 ppb** 0.000061 98.1790%	**<1 ppb** 0.000062 99.7543%	**<1 ppb** 0.000063 99.9668%
Chloroform	**3 ppb** 8 ppb	**1 ppb** 0.000125 71.9610%	**<1 ppb** 0.000173 92.1381%	**<1 ppb** 0.000183 97.7956%	**<1 ppb** 0.000186 99.3819%
Tetrachloroethylene	**1 ppb** 0 ppb	**<1 ppb** 0.000052 83.5167%	**<1 ppb** 0.000061 97.2830%	**<1 ppb** 0.000062 99.5522%	**<1 ppb** 0.000062 99.9262%
Trichloroethylene	**5 ppb** 5 ppb	**1 ppb** 0.000250 80.4613%	**<1 ppb** 0.000301 96.1824%	**<1 ppb** 0.000310 99.2541%	**<1 ppb** 0.000312 99.8543%

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Report generated: 7/9/1999

Table B-2

Single Site Treatment Facility Evaluation Results for RSA-96
Redstone Arsenal, Madison County, Alabama

RSA 96	Expected Concentration in Treatment Stream µg/L	Liquid Carbon Usage (lb/dy)	Primary Air Stripping Treatment Effluent µg/L	Carbon Usage Liquid Polishing (lb/dy)	Air Stream at Stack (mg/m^3)	Total Vapor Phase Release (lb/dy)	Vapor Phase Carbon Usage (lb/dy)	UV OX [C] effluent µg/L	Air Strip [C] effluent µg/L	Air Stream at Stack (mg/m^3)	Vapor Phase Release (lb/dy)
TDS	270										
1,1 Dichlorethene	0	0	0	0	0	0.0	0	0	0	0	0
1,2 Dichloroethane	0	0	0	0	0	0	0	0	0	0	0
1,2 Dichlorethene	374	503	1	1	5	1	3	0.01	0	0.0002	0.00004
Carbon Tetrachloride	0	0	0	0	0	0	0	0	0	0	0
Chloroform	0	0	0	0	0.00	0.00	0.00	0	0	0	0
1,1,1 Trichloroethane	587	1581	0	0	7	2	6	211	3	3	0.56
Tetrachloroethene	0	0	0	0	0	0	0	0	0	0	0
Trichloroethene	33789	3540	3	1	423	91	240	1.2	0.03	0.0	0.00
	Total (lb/dy)	5624		2		94	248				1

Notes:
Treatment stream concentrations are weighted averages, weighted by the well's contribution to the total discharge for the site.
Carbon loading for TCE concentrations above 1000 µg/L is 28 mg/g carbon
Cumulative discharge rate from all wells (g| 225
Primary air stripping based on one 4 tray 2400 cfm gpm (Model 41241).
UV-Oxidation-Air Stripper treatment unit uses a 180kW UV/Os System and two tray 1800 cfm (Model 31221) air stripper.

ShallowTray
low profile air strippers

stem Performance Estimate

Client and Proposal Information:

Redstone Arsenal OU-10
Air Stripping rimary Treatment
RSA-96 Single Site

Model Chosen: 41200
Water Flow Rate: 225.0 gpm
Air Flow Rate: 2400 cfm
Water Temp: 56.0 F
Air Temp: 60.0 F
A/W Ratio: 79.8
Safety Factor: 5%

Contaminant	Untreated Influent Effluent Target	Model 41211 Effluent Water Air(lbs/hr) % removal	Model 41221 Effluent Water Air(lbs/hr) % removal	Model 41231 Effluent Water Air(lbs/hr) % removal	Model 41241 Effluent Water Air(lbs/hr) % removal
1,1,1-Trichloroethane	**587 ppb** 200 ppb	**42 ppb** 0.061340 92.9925%	**3 ppb** 0.065729 99.5089%	**<1 ppb** 0.066044 99.9656%	**<1 ppb** 0.066065 99.9976%
1,1-Dichloroethylene	**1 ppb** 0 ppb	**<1 ppb** 0.000107 95.4457%	**<1 ppb** 0.000112 99.7926%	**<1 ppb** 0.000113 99.9906%	**<1 ppb** 0.000113 99.9996%
c-1,2-Dichloroethylen	**374 ppb** 70 ppb	**83 ppb** 0.032752 78.0160%	**19 ppb** 0.039955 95.1670%	**4 ppb** 0.041643 98.9375%	**1 ppb** 0.041981 99.7664%
Trichloroethylene	**33789 ppb** 5 ppb	**3214 ppb** 3.441203 90.4891%	**306 ppb** 3.768497 99.0954%	**30 ppb** 3.799561 99.9140%	**3 ppb** 3.802599 99.9918%
Tetrachloroethylene	**1 ppb** 0 ppb	**<1 ppb** 0.000104 92.5391%	**<1 ppb** 0.000112 99.4433%	**<1 ppb** 0.000113 99.9585%	**<1 ppb** 0.000113 99.9969%
Chloroform	**1 ppb** 0 ppb	**<1 ppb** 0.000095 84.1061%	**<1 ppb** 0.000110 97.4738%	**<1 ppb** 0.000112 99.5985%	**<1 ppb** 0.000112 99.9362%
Carbon Tetrachloride	**1 ppb** 0 ppb	**<1 ppb** 0.000106 94.3928%	**<1 ppb** 0.000112 99.6856%	**<1 ppb** 0.000113 99.9824%	**<1 ppb** 0.000113 99.9990%

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ShallowTray
low profile air strippers

System Performance Estimate

Client and Proposal Information:

Redstone Arsenal OU-10
UV/OX Primary Treatment
RSA-96 Single Site

Model Chosen:	31200
Water Flow Rate:	225.0 gpm
Air Flow Rate:	1800 cfm
Water Temp:	56.0 F
Air Temp:	60.0 F
A/W Ratio:	59.8
Safety Factor:	5%

Contaminant	**Untreated Influent** Effluent Target	**Model 31211 Effluent Water** Air(lbs/hr) % removal	$\boxed{\textbf{Model 31221}}$ **Effluent Water** Air(lbs/hr) % removal	**Model 31231 Effluent Water** Air(lbs/hr) % removal	**Model 31241 Effluent Water** Air(lbs/hr) % removal
1,1,1-Trichloroethane	**211 ppb** 200 ppb	**24 ppb** 0.021047 88.7455%	**3 ppb** 0.023410 98.7334%	**1 ppb** 0.023635 99.8574%	**<1 ppb** 0.023744 99.9840%
1,1-Dichloroethylene	**1 ppb** 0 ppb	**<1 ppb** 0.000104 92.8064%	**<1 ppb** 0.000112 99.4825%	**<1 ppb** 0.000113 99.9628%	**<1 ppb** 0.000113 99.9973%
c-1,2-Dichloroethylene	**1 ppb** 0 ppb	**1 ppb** <.000001 70.7928%	**<1 ppb** 0.000103 91.4694%	**<1 ppb** 0.000110 97.5084%	**<1 ppb** 0.000112 99.2723%
Trichloroethylene	**1 ppb** 1 ppb	**<1 ppb** 0.000112 83.0952%	**<1 ppb** 0.000131 97.1423%	**<1 ppb** 0.000134 99.5169%	**<1 ppb** 0.000135 99.9183%
Tetrachloroethylene	**1 ppb** 0 ppb	**<1 ppb** 0.000097 85.9458%	**<1 ppb** 0.000110 98.0248%	**<1 ppb** 0.000112 99.7224%	**<1 ppb** 0.000113 99.9610%
Chloroform	**3 ppb** 0 ppb	**1 ppb** 0.000225 74.9923%	**<1 ppb** 0.000317 93.7462%	**<1 ppb** 0.000332 98.4361%	**<1 ppb** 0.000336 99.6089%
Carbon Tetrachloride	**1 ppb** 0 ppb	**<1 ppb** 0.000100 88.6905%	**<1 ppb** 0.000111 98.7210%	**<1 ppb** 0.000112 99.8553%	**<1 ppb** 0.000113 99.9836%

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Table B-3

Single Site Treatment Facility Evaluation Results for RS715 RSA-95
Redstone Arsenal, Madison County, Alabama

RSA 95	Expected Concentration In Treatment Stream µg/L	Liquid Carbon Usage (lb/dy)	Primary Air Stripping Treatment Effluent µg/L	Carbon Usage Liquid Polishing (lb/dy)	Air Stream (mg/m³)	Vapor Phase Release (lb/dy)	Vapor Phase Carbon (lb/dy)	UV OX [C] effluent µg/L	Air Strip [C] effluent µg/L	Air Stream (mg/m³)	Vapor Phase Release (lb/dy)
1,1 Dichlorethene	130	73	0	0	1.350	0.109	0.3	0	0	3E-17	3.E-18
1,1 Dichloroethane	0.5	2.6	0	0	0.005	0	0.0039	0.02	0	2E-04	1.E-05
1,2 Dichlorethene	17	7	0	0	0.18	0.01	0.04	0	0	8E-16	7.E-17
Carbon Tetrachloride	5	9.7	0	0	0.05	0.00	0.04	0	0	2E-03	2.E-04
Chloroform	36	101	0	0	0.4	0.0	0.60	1	0	0.01	1.E-03
1,1,1 Trichlorethane	2100	1760	1	1	22	2	6	78	1	1	0.06
Tetrachloroethene	2	0.34	0	0	0.02	0	0.004	0	0	1E-09	9.E-11
Trichlorethene	8000	329	2	0	83	7	18	0	0	4E-13	3.E-14
	Total (lb/dy)	2283		1		9	25				0.07

Notes:
Treatment stream concentrations are weighted averages, weighted by the well's contribution to the total discharge for the site.
Cumulative discharge rate from all wells (gpm) 70
Primary air stripping uses one 3 tray 900 cfm shallow tray unit (Model 3631). Vapor phase polishing is not required.
UV-Oxidation-Air Stripper treatment unit uses one 180kW UV/Ox system and one 2 tray 600 cfm (Model 2621) unit. No polishing is necessary.

ShallowTray
low profile air strippers

System Performance Estimate

Client and Proposal Information:

Redstone Arsenal OU-10
Air Stripping Primary Treatment
RSA-95 RS715

Model Chosen:	3600
Water Flow Rate:	70.0 gpm
Air Flow Rate:	900 cfm
Water Temp:	56.0 F
Air Temp:	60.0 F
A/W Ratio:	96.2
Safety Factor:	5%

Contaminant	**Untreated Influent** Effluent Target	**Model 3611 Effluent Water** Air(lbs/hr) % removal	**Model 3621 Effluent Water** Air(lbs/hr) % removal	$\boxed{\text{Model 3631}}$ **Effluent Water** Air(lbs/hr) % removal	**Model 3641 Effluent Water** Air(lbs/hr) % removal	**Model 3651 Effluent Water** Air(lbs/hr) % removal
1,1,1-Trichloroethane	**2100 ppb** 200 ppb	**112 ppb** 0.069611 94.6804%	**6 ppb** 0.073322 99.7170%	**1 ppb** 0.073497 99.9849%	**<1 ppb** 0.073532 99.9992%	**<1 ppb** 0.073532 100.0000%
1,1-Dichloroethylene	**10 ppb** 7 ppb	**1 ppb** 0.000315 97.0890%	**<1 ppb** 0.000350 99.9153%	**<1 ppb** 0.000350 99.9975%	**<1 ppb** 0.000350 99.9999%	**<1 ppb** 0.000350 100.0000%
c-1,2-Dichloroethylene	**17 ppb** 5 ppb	**4 ppb** 0.000455 82.2749%	**1 ppb** 0.000560 96.8582%	**<1 ppb** 0.000592 99.4431%	**<1 ppb** 0.000595 99.9013%	**<1 ppb** 0.000595 99.9825%
Carbon Tetrachloride	**5 ppb** 1 ppb	**<1 ppb** 0.000170 97.2355%	**<1 ppb** 0.000175 99.9236%	**<1 ppb** 0.000175 99.9979%	**<1 ppb** 0.000175 99.9999%	**<1 ppb** 0.000175 100.0000%
Chloroform	**36 ppb** 8 ppb	**4 ppb** 0.001120 89.9299%	**1 ppb** 0.001226 98.9859%	**<1 ppb** 0.001259 99.8979%	**<1 ppb** 0.001260 99.9897%	**<1 ppb** 0.001261 99.9990%
Tetrachloroethylene	**2 ppb** 0 ppb	**<1 ppb** 0.000067 96.0593%	**<1 ppb** 0.000070 99.8447%	**<1 ppb** 0.000070 99.9939%	**<1 ppb** 0.000070 99.9998%	**<1 ppb** 0.000070 100.0000%
Trichloroethylene	**8000 ppb** 5 ppb	**427 ppb** 0.265172 94.6737%	**23 ppb** 0.279318 99.7163%	**2 ppb** 0.280053 99.9849%	**<1 ppb** 0.280121 99.9992%	**<1 ppb** 0.280123 100.0000%

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ShallowTray
low profile air strippers

System Performance Estimate

Client and Proposal Information:

Redstone Arsenal OU-10
UV/OX Primary Treatment
RSA-95 RS715

Model Chosen: 2600
Water Flow Rate: 70.0 gpm
Air Flow Rate: 600 cfm
Water Temp: 56.0 F
Air Temp: 60.0 F
A/W Ratio: 64.1
Safety Factor: 5%

Contaminant	Untreated Influent / Effluent Target	Model 2611 Effluent Water / Air(lbs/hr) / % removal	Model 2621 Effluent Water / Air(lbs/hr) / % removal	Model 2631 Effluent Water / Air(lbs/hr) / % removal	Model 2641 Effluent Water / Air(lbs/hr) / % removal	Model 2651 Effluent Water / Air(lbs/hr) / % removal
1,1,1-Trichloroethane	**78 ppb** 20 ppb	**8 ppb** 0.002451 89.9018%	**1 ppb** 0.002696 98.9803%	**<1 ppb** 0.002728 99.8970%	**<1 ppb** 0.002731 99.9896%	**<1 ppb** 0.002731 99.9989%
1,1-Dichloroethylene	**1 ppb** 7 ppb	**<1 ppb** 0.000033 93.2294%	**<1 ppb** 0.000035 99.5416%	**<1 ppb** 0.000035 99.9690%	**<1 ppb** 0.000035 99.9979%	**<1 ppb** 0.000035 99.9999%
c-1,2-Dichloroethylene	**1 ppb** 1 ppb	**1 ppb** <.000001 73.2294%	**<1 ppb** 0.000033 92.8333%	**<1 ppb** 0.000034 98.0814%	**<1 ppb** 0.000035 99.4864%	**<1 ppb** 0.000035 99.8625%
Carbon Tetrachloride	**1 ppb** 1 ppb	**<1 ppb** 0.000031 89.9312%	**<1 ppb** 0.000035 98.9862%	**<1 ppb** 0.000035 99.8979%	**<1 ppb** 0.000035 99.9897%	**<1 ppb** 0.000035 99.9990%
Chloroform	**3 ppb** 8 ppb	**1 ppb** 0.000070 76.8039%	**<1 ppb** 0.000099 94.6194%	**<1 ppb** 0.000104 98.7519%	**<1 ppb** 0.000105 99.7105%	**<1 ppb** 0.000105 99.9328%
Tetrachloroethylene	**1 ppb** 0 ppb	**<1 ppb** 0.000031 87.3452%	**<1 ppb** 0.000034 98.3986%	**<1 ppb** 0.000035 99.7973%	**<1 ppb** 0.000035 99.9743%	**<1 ppb** 0.000035 99.9968%
Trichloroethylene	**5 ppb** 5 ppb	**1 ppb** 0.000140 84.6313%	**<1 ppb** 0.000171 97.6380%	**<1 ppb** 0.000174 99.6370%	**<1 ppb** 0.000175 99.9442%	**<1 ppb** 0.000175 99.9914%

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Table B-4

Single Site Treatment Facility Evaluation Results for RS593 and RS730 RSA-96
Redstone Arsenal, Madison County, Alabama

RSA 96	Expected Concentration in Treatment Stream	Liquid Carbon Usage (lb/dy)	Primary Air Stripping Treatment Effluent µg/L	Carbon Usage Liquid Polishing (lb/dy)	Air Stream at Stack (mg/m^3)	Total Vapor Phase Release (lb/dy)	Vapor Phase Carbon Usage (lb/dy)	UV OX [C] effluent µg/L	Air Strip [C] effluent µg/L	Air Stream at Stack (mg/m^3)	Vapor Phase Release (lb/dy)
1,1 Dichlorethene	0	0	0	0	0	0.0	0	0	0	0	0
1,2 Dichloroethane	0	0	0	0	0	0	0	0	0	0	0
1,2 Dichlorethene	751	1236	1	1	11	2	6	0.17	0.01	0.0025	0.00053
Carbon Tetrachloride	0	0	0	0	0	0	0	0	0	0	0
Chloroform	0	0	0	0	0	0	0	0	0	0	0
1,1,1 Trichloroethane	592	1949	0	0	9	2	7	256	2.54	4	0.84
Tetrachloroethene	0	0	0	0	0	0	0	0	0	0	0
Trichloroethene	36909	4694	1	0	565	122	320	8.5	0.19	0.1	0.03
	Total (lb/dy)	7879		1		126	333				1

Notes:
VOC concentrations are in µg/L, all others are mg/L
Treatment stream concentrations are weighted averages, weighted by the well's contribution to the total discharge for the site.
Cumulative discharge rate from all wells = 275
Primary air stripper - 3-tray 2400 cfm treatment unit (Model 41211). Carbon polishing required for both liquid vapor effluent streams.
Carbon loading for TCE concentrations above 1000 µg/L is 28 mg/g carbon
UV-Oxidation-Air Stripper treatment unit - one 180kW UV/Os system and one 2-tray 2400 cfm air stripper (Model 41211). No polishing required for " effluent streams

ShallowTray
low profile air strippers

System Performance Estimate

Client and Proposal Information:

Redstone Arsenal OU-10
Air Stripping Primary Treatment
RSA-96 RS730 and RS593

Model Chosen:	41200
Water Flow Rate:	140.0 gpm
Air Flow Rate:	2400 cfm
Water Temp:	56.0 F
Air Temp:	60.0 F
A/W Ratio:	128.2
Safety Factor:	5%

Contaminant	Untreated Influent Effluent Target	Model 41211 Effluent Water Air(lbs/hr) % removal	Model 41221 Effluent Water Air(lbs/hr) % removal	Model 41231 Effluent Water Air(lbs/hr) % removal	Model 41241 Effluent Water Air(lbs/hr) % removal
1,1,1-Trichloroethane	**592 ppb** 200 ppb	**22 ppb** 0.039918 96.3382%	**1 ppb** 0.041388 99.8659%	**<1 ppb** 0.041456 99.9951%	**<1 ppb** 0.041458 99.9998%
1,1-Dichloroethylene	**10 ppb** 7 ppb	**<1 ppb** 0.000689 98.3964%	**<1 ppb** 0.000700 99.9743%	**<1 ppb** 0.000700 99.9996%	**<1 ppb** 0.000700 100.0000%
c-1,2-Dichloroethylen	**751 ppb** 5 ppb	**77 ppb** 0.047201 89.8229%	**8 ppb** 0.052033 98.9643%	**1 ppb** 0.052523 99.8946%	**<1 ppb** 0.052588 99.9893%
Carbon Tetrachloride	**5 ppb** 1 ppb	**<1 ppb** 0.000347 99.1463%	**<1 ppb** 0.000350 99.9927%	**<1 ppb** 0.000350 99.9999%	**<1 ppb** 0.000350 100.0000%
Chloroform	**36 ppb** 8 ppb	**2 ppb** 0.002381 95.2828%	**<1 ppb** 0.002516 99.7775%	**<1 ppb** 0.002521 99.9895%	**<1 ppb** 0.002521 99.9995%
Tetrachloroethylene	**2 ppb** 0 ppb	**<1 ppb** 0.000138 98.6356%	**<1 ppb** 0.000140 99.9814%	**<1 ppb** 0.000140 99.9997%	**<1 ppb** 0.000140 100.0000%
Trichloroethylene	**36909 ppb** 5 ppb	**751 ppb** 2.532175 97.9677%	**16 ppb** 2.583648 99.9587%	**1 ppb** 2.584698 99.9992%	**<1 ppb** 2.584768 100.0000%

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ShallowTray
low profile air strippers

System Performance Estimate

Client and Proposal Information:

Redstone Arsenal OU-10
UV/OX Primary Treatment
RSA-96 RS730 and RS593

Model Chosen:	41200
Water Flow Rate:	275.0 gpm
Air Flow Rate:	2400 cfm
Water Temp:	56.0 F
Air Temp:	60.0 F
A/W Ratio:	65.3
Safety Factor:	5%

Contaminant	**Untreated Influent** Effluent Target	**Model 41211 Effluent Water** Air(lbs/hr) % removal	**Model 41221 Effluent Water** Air(lbs/hr) % removal	**Model 41231 Effluent Water** Air(lbs/hr) % removal	**Model 41241 Effluent Water** Air(lbs/hr) % removal
1,1,1-Trichloroethane	**256 ppb** 20 ppb	**26 ppb** 0.031639 90.1994%	**3 ppb** 0.034803 99.0395%	**<1 ppb** 0.035182 99.9059%	**<1 ppb** 0.035212 99.9908%
1,1-Dichloroethylene	**1 ppb** 7 ppb	**<1 ppb** 0.000128 93.3713%	**<1 ppb** 0.000137 99.5606%	**<1 ppb** 0.000138 99.9709%	**<1 ppb** 0.000138 99.9981%
c-1,2-Dichloroethylene	**1 ppb** 1 ppb	**1 ppb** <.000001 73.7481%	**<1 ppb** 0.000128 93.1084%	**<1 ppb** 0.000135 98.1908%	**<1 ppb** 0.000137 99.5251%
Carbon Tetrachloride	**1 ppb** 1 ppb	**<1 ppb** 0.000124 90.2771%	**<1 ppb** 0.000136 99.0546%	**<1 ppb** 0.000137 99.9081%	**<1 ppb** 0.000138 99.9911%
Chloroform	**1 ppb** 8 ppb	**<1 ppb** 0.000106 77.3223%	**<1 ppb** 0.000130 94.8572%	**<1 ppb** 0.000136 98.8337%	**<1 ppb** 0.000137 99.7355%
Tetrachloroethylene	**1 ppb** 0 ppb	**<1 ppb** 0.000121 87.7382%	**<1 ppb** 0.000135 98.4965%	**<1 ppb** 0.000137 99.8156%	**<1 ppb** 0.000138 99.9774%
Trichloroethylene	**8 ppb** 5 ppb	**2 ppb** 0.000894 85.0654%	**<1 ppb** 0.001143 97.7696%	**<1 ppb** 0.001165 99.6669%	**<1 ppb** 0.001169 99.9502%

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Table B-5

Air Stripping and Carbon Adsorption Combined Full Waste Stream
RSA-95 and RSA-96
Redstone Arsenal, Madison County, Alabama

	Discharge Limitation	Expected Treatment Stream Concentration (µg/L)	Air Stripper Effluent (µg/L)	Liquid Phase Carbon Consumption[a] (lb/dy)	Air Stream at Stack (mg/m^3)	Mass in Air Stream[b] (lb/day)	Vapor Phase Carbon Consumption[b] (lb/dy)
1,1 Dichloroethene	7	39	0	0	0.4	0.08	0
1,1 Dichloroethane	-	0	0	0	0	0	0
1,2 Dichloroethene	70	243	1	3	2	0.51	1
Carbon Tertachlori	5	1	0	0	0	0	0.03
Chloroform	80	7	0	0	0	0	0
1,1,1 Trichloroetha	200	877	0	0	9	1.8	7
Tetrachloroethene	5	0	0	0	0	0.00	0.00
Trichloroethene	5	23779	2	2	231	50	131
Total Carbon Consumption (lb/day)[c]				**10**		**105**	**279**

Note:

[a] Liquid phase treatment option included as a contingency

[b] Total flow to treatment system is split into two 175 gpm streams. Mass and carbon usage is calculated on a per stream basis.

[c] Total Carbon consumption is calculated for both treatment streams.

Air stripping calculations are based on using two 4-tray 2400 cfm air stripping (Model 41241) units.

ShallowTray
low profile air strippers

System Performance Estimate

Client and Proposal Information:

Redstone Arsenal OU-10
Air Stripping Primary Treatment
RSA-95 and RSA-96 Full Stream

Model Chosen:	41200
Water Flow Rate:	175.0 gpm
Air Flow Rate:	2400 cfm
Water Temp:	56.0 F
Air Temp:	60.0 F
A/W Ratio:	102.6
Safety Factor:	5%

Contaminant	Untreated Influent Effluent Target	Model 41211 Effluent Water Air(lbs/hr) % removal	Model 41221 Effluent Water Air(lbs/hr) % removal	$\boxed{\text{Model 41231}}$ Effluent Water Air(lbs/hr) % removal	Model 41241 Effluent Water Air(lbs/hr) % removal
1,1,1-Trichloroethane	**877 ppb** 200 ppb	**43 ppb** 0.073007 95.1215%	**3 ppb** 0.076509 99.7620%	**<1 ppb** 0.076762 99.9884%	**<1 ppb** 0.076771 99.9994%
1,1-Dichloroethylene	**39 ppb** 7 ppb	**1 ppb** 0.003326 97.4909%	**<1 ppb** 0.003412 99.9370%	**<1 ppb** 0.003414 99.9984%	**<1 ppb** 0.003414 100.0000%
c-1,2-Dichloroethylene	**243 ppb** 70 ppb	**39 ppb** 0.017858 83.9903%	**7 ppb** 0.020659 97.4369%	**1 ppb** 0.021184 99.5897%	**<1 ppb** 0.021258 99.9343%
Trichloroethylene	**23779 ppb** 5 ppb	**1021 ppb** 1.992202 95.7080%	**44 ppb** 2.077727 99.8158%	**2 ppb** 2.081404 99.9921%	**<1 ppb** 2.081572 99.9997%
Tetrachloroethylene	**1 ppb** 0 ppb	**<1 ppb** 0.000085 96.8929%	**<1 ppb** 0.000087 99.9035%	**<1 ppb** 0.000088 99.9970%	**<1 ppb** 0.000088 99.9999%
Chloroform	**7 ppb** 1 ppb	**1 ppb** 0.000525 91.5036%	**<1 ppb** 0.000608 99.2781%	**<1 ppb** 0.000612 99.9387%	**<1 ppb** 0.000613 99.9948%
Carbon Tetrachloride	**1 ppb** 0 ppb	**<1 ppb** 0.000086 97.8755%	**<1 ppb** 0.000087 99.9549%	**<1 ppb** 0.000088 99.9990%	**<1 ppb** 0.000088 100.0000%

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Table B-6

UV-Oxidation and Air Stripping. RSA-95 and RSA-96 Redstone Arsenal, Madison County, Alabama

	Discharge Limitation	Expected Treatment Stream Concentration (µg/L)	UV OX [C] Effluent (µg/L)	Air Stripper Effluent mg/L				Air Stream at Stack (mg/m^3)	Mass in Air Stream (lb/day)
				Number of Trays					
				1	2	3	4		
1,1 Dichloroethene	7	39	0.00	0	0	0	0	0	0
1,1 Dichloroethane	-	0	0	0	0	0	0	0	0
1,2 Dichloroethene	70	243	0.0	0	0	0	0	0	0
Carbon Tertachloride	5	1	0	0	0	0	0	0	0
Chloroform	80	7	2	0	0	0	0	0	0
1,1,1 Trichloroethane	200	877	235	17	3	0	0	3	0.5
Tetrachloroethene	5	1	0	0	0	0	0	0	0
Trichloroethene	5	23779	123	13	2	0	0	2	0.3
								Total Mass Emissions (lb/dy)	1.5

Notes:

[a] Total flow from UV treatment plant is split into two 175 gpm streams. Air emissions are calculated on a per stream basis, using 1800 cfm 3-tray unit (Model 31231). Total mass is for both treatment streams.

UV-Oxidation unit is a 180kW UV/Ox System. One unit is required for each treatment stream.

ShallowTray
low profile air strippers

System Performance Estimate

Client and Proposal Information:

Redstone Arsenal OU-10
UV/OX Primary Treatment
RSA-95 and RSA-96 Full Stream

Model Chosen:	31200
Water Flow Rate:	175.0 gpm
Air Flow Rate:	1800 cfm
Water Temp:	56.0 F
Air Temp:	60.0 F
A/W Ratio:	76.9
Safety Factor:	5%

Contaminant	Untreated Influent / Effluent Target	Model 31211 Effluent Water / Air(lbs/hr) / % removal	Model 31221 Effluent Water / Air(lbs/hr) / % removal	$\boxed{\text{Model 31231}}$ Effluent Water / Air(lbs/hr) / % removal	Model 31241 Effluent Water / Air(lbs/hr) / % removal
1,1,1-Trichloroethane	**235 ppb** 200 ppb	**18 ppb** 0.018996 92.5686%	**2 ppb** 0.020396 99.4477%	**<1 ppb** 0.020563 99.9590%	**<1 ppb** 0.020571 99.9969%
1,1-Dichloroethylene	**10 ppb** 7 ppb	**1 ppb** 0.000788 95.0543%	**<1 ppb** 0.000873 99.7554%	**<1 ppb** 0.000875 99.9879%	**<1 ppb** 0.000875 99.9994%
c-1,2-Dichloroethylene	**5 ppb** 0 ppb	**2 ppb** 0.000263 77.3081%	**1 ppb** 0.000350 94.8508%	**<1 ppb** 0.000433 98.8315%	**<1 ppb** 0.000437 99.7349%
Trichloroethylene	**123 ppb** 5 ppb	**13 ppb** 0.009629 89.5035%	**2 ppb** 0.010592 98.8982%	**<1 ppb** 0.010755 99.8844%	**<1 ppb** 0.010766 99.9879%
Tetrachloroethylene	**1 ppb** 0 ppb	**<1 ppb** 0.000080 91.6835%	**<1 ppb** 0.000087 99.3084%	**<1 ppb** 0.000087 99.9425%	**<1 ppb** 0.000088 99.9952%
Chloroform	**7 ppb** 1 ppb	**2 ppb** 0.000438 82.8231%	**<1 ppb** 0.000595 97.0495%	**<1 ppb** 0.000610 99.4932%	**<1 ppb** 0.000612 99.9129%
Carbon Tetrachloride	**1 ppb** 0 ppb	**<1 ppb** 0.000082 93.6761%	**<1 ppb** 0.000087 99.6001%	**<1 ppb** 0.000088 99.9747%	**<1 ppb** 0.000088 99.9984%

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Report generated: 7/9/1999

Table B-7

Air Stripping and Carbon Adsorption RS715 at RSA-95 and RS593 and RS730 at RSA-96 Redstone Arsenal, Madison County, Alabama

	Discharge Limitation	Expected Treatment Stream Concentration (µg/L)	Air Stripper Effluent (µg/L)	Liquid Phase Carbon[a] (lb/dy)	Air Stream at Stack (mg/m^3)	Mass in Air Stream[b] (lb/day)	Vapor Phase Carbon[b] (lb/dy)
1,1 Dichloroethene	7	26	0	0	0.5	0.11	0
1,1 Dichloroethane	-	0	0	0	0	0	0
1,2 Dichloroethene	70	602	11	22	11	2.44	6
Carbon Tertachloride	5	1	0	0	0	0	0.04
Chloroform	80	7	0	0	0	0	1
1,1,1 Trichloroethane	200	898	1	0	17	3.7	13
Tetrachloroethene	5	0	0	0	0	0.00	0.00
Trichloroethene	5	31043	61	36	595	128	337
Total Carbon Consumption (lb/day)[c]				**58**		**134**	**357**

[a]Liquid phase treatment carbon usage.
[b]Flow to treatment streams is 345 gpm.
[c]Total Carbon usage is calculated.
Air stripping calculations are based on a 4-tray 2400 cfm unit (Model 41241).

ShallowTray
low profile air strippers

System Performance Estimate

Client and Proposal Information:

Redstone Arsenal OU-10
Air Stripping Primary Treatment
RSA-95 RS730
RSA-96 RS730 and RS593

Model Chosen:	41200
Water Flow Rate:	345.0 gpm
Air Flow Rate:	2400 cfm
Water Temp:	56.0 F
Air Temp:	60.0 F
A/W Ratio:	52.0
Safety Factor:	5%

Contaminant	**Untreated Influent** Effluent Target	**Model 41211 Effluent Water** Air(lbs/hr) % removal	**Model 41221 Effluent Water** Air(lbs/hr) % removal	**Model 41231 Effluent Water** Air(lbs/hr) % removal	**Model 41241 Effluent Water** Air(lbs/hr) % removal
1,1,1-Trichloroethane	**898 ppb** 200 ppb	**118 ppb** 0.134609 86.8631%	**16 ppb** 0.152212 98.2742%	**3 ppb** 0.154456 99.7733%	**1 ppb** 0.154801 99.9702%
1,1-Dichloroethylene	**26 ppb** 7 ppb	**3 ppb** 0.003969 91.8358%	**<1 ppb** 0.004457 99.3335%	**<1 ppb** 0.004485 99.9456%	**<1 ppb** 0.004487 99.9956%
c-1,2-Dichloroethylen	**602 ppb** 70 ppb	**218 ppb** 0.066269 63.9058%	**79 ppb** 0.090257 86.9721%	**29 ppb** 0.098886 95.2977%	**11 ppb** 0.101992 98.3027%
Carbon Tetrachloride	**5 ppb** 1 ppb	**1 ppb** 0.000690 85.2796%	**<1 ppb** 0.000844 97.8331%	**<1 ppb** 0.000860 99.6810%	**<1 ppb** 0.000862 99.9530%
Chloroform	**7 ppb** 5 ppb	**3 ppb** 0.000690 70.3379%	**1 ppb** 0.001035 91.2016%	**<1 ppb** 0.001177 97.3902%	**<1 ppb** 0.001199 99.2259%
Tetrachloroethylene	**2 ppb** 0 ppb	**1 ppb** 0.000173 82.1709%	**<1 ppb** 0.000334 96.8212%	**<1 ppb** 0.000343 99.4333%	**<1 ppb** 0.000345 99.8990%
Trichloroethylene	**31043 ppb** 5 ppb	**6514 ppb** 4.233117 79.0177%	**1367 ppb** 5.121365 95.5974%	**287 ppb** 5.307747 99.0762%	**61 ppb** 5.346749 99.8062%

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Report generated: 7/9/1999

Table B-8

Air Stripping and Carbon Adsorption
RS715 at RSA-95 and RS593 and RS730 at RSA-96
Redstone Arsenal, Madison County, Alabama

	Discharge Limitation	Expected Treatment Stream Concentration (µg/L)	Air Stripper Effluent (µg/L)	Liquid Phase Carbon[a] (lb/dy)	Air Stream at Stack (mg/m^3)	Mass in Air Stream[b] (lb/day)	Vapor Phase Carbon[b] (lb/dy)
1,1 Dichloroethene	7	26	0	0	0.3	0.05	0
1,1 Dichloroethane	-	0	0	0	0	0	0
1,2 Dichloroethene	70	602	3	0	6	1.24	3
Carbon Tertachloride	5	1	0	0	0	0	0.02
Chloroform	80	7	0	0	0	0	0
1,1,1 Trichloroethane	200	898	0	0	9	1.9	7
Tetrachloroethene	5	0	0	0	0	0.00	0.00
Trichloroethene	5	31043	4	1	298	64	169
Total Carbon Consumption (lb/day)[c]				**2**		**135**	**358**

[a] Liquid phase treatment option included as a contingency
[b] Flow to split into two treatment streams of 173 gpm.
[c] Total Carbon usage is calculated.
Air stripping calculations are based on a 4-tray 2400 cfm unit (Model 41241).

ShallowTray
low profile air strippers

System Performance Estimate

Client and Proposal Information:

Redstone Arsenal OU-10
Air Stripping Primary Treatment
RSA-95 RS730
RSA-96 RS730 and RS593

Model Chosen:	41200
Water Flow Rate:	180.0 gpm
Air Flow Rate:	2400 cfm
Water Temp:	56.0 F
Air Temp:	60.0 F
A/W Ratio:	99.7
Safety Factor:	5%

Contaminant	Untreated Influent Effluent Target	Model 41211 Effluent Water Air(lbs/hr) % removal	Model 41221 Effluent Water Air(lbs/hr) % removal	$\boxed{\text{Model 41231}}$ Effluent Water Air(lbs/hr) % removal	Model 41241 Effluent Water Air(lbs/hr) % removal
1,1,1-Trichloroethane	**898 ppb** 200 ppb	**46 ppb** 0.076714 94.9357%	**3 ppb** 0.080585 99.7435%	**<1 ppb** 0.080845 99.9870%	**<1 ppb** 0.080855 99.9993%
1,1-Dichloroethylene	**26 ppb** 7 ppb	**1 ppb** 0.002251 97.3252%	**<1 ppb** 0.002339 99.9285%	**<1 ppb** 0.002341 99.9981%	**<1 ppb** 0.002341 99.9999%
c-1,2-Dichloroethylene	**602 ppb** 70 ppb	**101 ppb** 0.045110 83.2323%	**17 ppb** 0.052673 97.1884%	**3 ppb** 0.053934 99.5286%	**1 ppb** 0.054114 99.9210%
Carbon Tetrachloride	**5 ppb** 1 ppb	**<1 ppb** 0.000439 97.6154%	**<1 ppb** 0.000450 99.9431%	**<1 ppb** 0.000450 99.9986%	**<1 ppb** 0.000450 100.0000%
Chloroform	**7 ppb** 5 ppb	**1 ppb** 0.000540 90.8463%	**<1 ppb** 0.000625 99.1621%	**<1 ppb** 0.000630 99.9233%	**<1 ppb** 0.000630 99.9930%
Tetrachloroethylene	**2 ppb** 0 ppb	**<1 ppb** 0.000174 96.5516%	**<1 ppb** 0.000180 99.8811%	**<1 ppb** 0.000180 99.9959%	**<1 ppb** 0.000180 99.9999%
Trichloroethylene	**31043 ppb** 5 ppb	**1465 ppb** 2.663193 95.2818%	**70 ppb** 2.788798 99.7774%	**4 ppb** 2.794741 99.9895%	**<1 ppb** 2.795087 99.9995%

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Report generated: 7/9/1999

Table B-9

UV-Oxidation and Air Stripping
RS715 at RSA-96 and RS593 and RS730 at RSA-96
Redstone Arsenal, Madison County, Alabama

	Discharge Limitation	Expected Treatment Stream Concentration (µg/L)	UV OX [C] Effluent (µg/L)	Air Stripper Effluent µg/L				Air Stream at Stack (mg/m^3)	Mass in Air Stream (lb/day)
				Number of Trays					
				1	2	3	4		
1,1 Dichloroethene	7	26	0	0.004	0	0	0	6.4E-04	1.E-04
1,1 Dichloroethane	-	0	0	0	0	0	0	0	0.0
1,2 Dichloroethene	70	602	1	0.3	0.1	0.0	0.0	0.01	3.E-03
Carbon Tertachloride	5	1	1	0	0	0	0	0.01	2.E-03
Chloroform	80	7	4	1	0	0	0	0.07	2.E-02
1,1,1 Trichloroethane	200	898	461	61	8	2	0	9	2
Tetrachloroethene	5	0	0	0	0	0	0	0	0
Trichloroethene	5	31043	1228	258	54	12	3	24	5
								Total Air Emissions	7

[a] Total flow from the UV/oxidation treatment plant is 345 gpm.
UV-Oxidation unit uses one 180kW UV/Ox System.
Air stream calculations based on using 4 tray, 2400 cfm unit (41241 Model)

ShallowTray
low profile air strippers

System Performance Estimate

Client and Proposal Information:

Redstone Arsenal OU-10
UV/OX Primary Treatment
RSA-95 RS730
RSA-96 RS730 and RS593

Model Chosen:	41200
Water Flow Rate:	345.0 gpm
Air Flow Rate:	2400 cfm
Water Temp:	56.0 F
Air Temp:	60.0 F
A/W Ratio:	52.0
Safety Factor:	5%

Contaminant	**Untreated Influent** Effluent Target	**Model 41211 Effluent Water** Air(lbs/hr) % removal	**Model 41221 Effluent Water** Air(lbs/hr) % removal	**Model 41231 Effluent Water** Air(lbs/hr) % removal	$\boxed{\textbf{Model 41241}}$ **Effluent Water** Air(lbs/hr) % removal
1,1,1-Trichloroethane	**461 ppb** 200 ppb	**61 ppb** 0.069030 86.8631%	**8 ppb** 0.078177 98.2742%	**2 ppb** 0.079212 99.7733%	**<1 ppb** 0.079534 99.9702%
1,1-Dichloroethylene	**10 ppb** 7 ppb	**1 ppb** 0.001553 91.8358%	**<1 ppb** 0.001714 99.3335%	**<1 ppb** 0.001725 99.9456%	**<1 ppb** 0.001726 99.9956%
c-1,2-Dichloroethylen	**10 ppb** 7 ppb	**4 ppb** 0.001035 63.9058%	**2 ppb** 0.001381 86.9721%	**1 ppb** 0.001553 95.2977%	**<1 ppb** 0.001696 98.3027%
Carbon Tetrachloride	**5 ppb** 1 ppb	**1 ppb** 0.000690 85.2796%	**<1 ppb** 0.000844 97.8331%	**<1 ppb** 0.000860 99.6810%	**<1 ppb** 0.000862 99.9530%
Chloroform	**7 ppb** 5 ppb	**3 ppb** 0.000690 70.3379%	**1 ppb** 0.001035 91.2016%	**<1 ppb** 0.001177 97.3902%	**<1 ppb** 0.001199 99.2259%
Tetrachloroethylene	**2 ppb** 0 ppb	**1 ppb** 0.000173 82.1709%	**<1 ppb** 0.000334 96.8212%	**<1 ppb** 0.000343 99.4333%	**<1 ppb** 0.000345 99.8990%
Trichloroethylene	**1228 ppb** 5 ppb	**258 ppb** 0.167399 79.0177%	**55 ppb** 0.202432 95.5974%	**12 ppb** 0.209852 99.0762%	**3 ppb** 0.211406 99.8062%

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Report generated: 7/9/1999

ATTACHMENT I

EXAMPLE CALCULATIONS

APPENDIX B

ENGINEERING CALCULATIONS FOR GROUNDWATER REMEDIATION AT RSA-95/96, OU-10, REDSTONE ARSENAL

GROUNDWATER TREATMENT SYSTEM

Prepared for:

Redstone Arsenal - Madison County, Alabama

Prepared by:

IT Corporation
312 Directors Drive
Knoxville, Tennessee

Project No. 772650

Originated By:	KT	Date:	05/14/99	Revision A:	____	Date:	8/17/1999
Checked By:	______	Date:	______	Revision B:	____	Date:	______
Approved By:	______	Date:	______	Revision C:	____	Date:	______

APPENDIX B

ENGINEERING CALCULATIONS FOR GROUNDWATER REMEDIATION AT RSA-95/96, OU-10

EXAMPLE CALCULATIONS FOR THE EVALUATION OF TREATMENT ALTERNATIVES

Table of Contents

B1. Example Calculation 1 for TCE. Table B-1. Single Site Treatment for RSA-95

B2. Example Calculation 2 for 1,1,1 TCA. Table B-1. Single Site Treatment for RSA-95

B3. Example Calculation 3 for TCE. Table B-2. Single Site Treatment for RSA-96

APPENDIX B

ENGINEERING CALCULATIONS FOR GROUNDWATER REMEDIATION
AT RSA-95/96, OU-10

B1. Example Calculation 1 for TCE: Table B-1. Single Site Treatment for RSA-95. Liquid-Phase Carbon Usage Column

Bases:

- Trichloroethylene (TCE) concentration = 5,760 ppb, Water Flow = 125 gpm
- For liquid-phase carbon loading from 5,760 ppb to 1000 ppb TCE
  Use 28 mg TCE/gram carbon (or 28/1000 gram TCE/gram or 0.028 lb TCE/ lb carbon)
  (or 35.7 lb carbon/ lb TCE) (as best loading) (from attached Isotherm Chart)
- For liquid-phase carbon loading from 1000 ppb to 5 ppb TCE
  Use 7 mg TCE/gram carbon (as best loading) (or 0.007 lb TCE / lb carbon)
  (or 142.86 lb carbon/ lb TCE)
- Equation for carbon consumption calculations:

Pound of Carbon Usage =
[(C mg VOC/L) x (3.785 L/gal) x (gal/day) x (22/ 10,000 lb/gram)] / [K mg VOC/gram Carbon]

TCE mass in untreated groundwater =

(5.760 mg/L x 3.785 L/gal x 125 gal/min x 1440 min/day) = 3,924,288 mgTCE/day (total)

(4.760 mg/L x 3.785 L/gal x 125 gal/min x 1440 min/day) = 3,242,988 mg TCE/day

(1.000 mg/L x 3.785 L/gal x 125 gal/min x 1440 min/day) = 681,300 mg TCE/day

Carbon Usage (liquid-phase) for TCE row (Table B-1) =

[(3,242,988 mg TCE/day) / (28 mg TCE / gram carbon)] / (454 gr/lb) = 255 lb carbon/day OR

[(3,242,988 mg TCE/day) / (28 mg TCE / gram carbon)] x [(22/ 10,000) lb/gram] = 255 lb carbon/day

[(681,300 mg TCE/day)/ (7 mg TCE / gram carbon)] / [454 gr/lb] = 214 lb carbon/day

---

Total = 469 lb carbon/day

B2. Example Calculation 2 for 1,1,1-TCA: Table B-1. Single Site Treatment for RSA-95 Liquid-Phase Carbon Usage Column

Bases:

- 1,1,1-TCA (trichloroethane) concentration = 1,399 ppb, Water Flow = 125 gpm
- For carbon loading from 1000 ppb to 5 ppb TCA
  Use 1 mg TCA/gram carbon (or 0.001 lb TCA / lb carbon) (or 1,000 lb carbon/lb TCA)
  (as best loading) (from attached Isotherm Chart)

TCA mass in untreated groundwater =

(1.399 mg/L x 3.785 L/gal x 125 gal/min x 1440 min/day) = 953,139 mg TCA/day

Carbon Usage (liquid-phase) for TCA row (Table B-1) =

[(953,139 TCE/day) / (1 mg TCE / gram carbon)] / [454 gram/lb] = **2,099 lb carbon/day**

B3. Example Calculation 3 for TCE: Table B-2. Single Site Treatment for RSA-96

Bases:

- TCE concentration = 33,789 ppb, Water Flow = 225 gpm

- For carbon loading from 33,789 ppb to 1000 ppb TCE
  Use 28 mg TCE/gram carbon (or 28/1000 gram TCE/gram or 0.028 lb TCE/ lb carbon)
  (or 35.7 lb carbon/ lb TCE) (as best loading) (from attached Isotherm Chart)

- For carbon loading from 1,000 ppb to 5 ppb TCE
  Use 7 mg TCE/gram carbon (as best loading) (or 0.007 lb TCE / lb carbon)
  (or 142.86 lb carbon/ lb TCE)

TCE mass in untreated groundwater (a different way of calculation) =

(33.789 mg/L x 3.785 L/gal x 225 gal/min x 1440 min/day) / (454,000 mg/lb) = 91.2 lb TCE/day
(32.789 mg/L x 3.785 L/gal x 225 gal/min x 1440 min/day) / (454,000 mg/lb) = 88.5 lb TCE/day
(1.000 mg/L x 3.785 L/gal x 225 gal/min x 1440 min/day) / (454,000 mg/lb) = 2.7 lb TCE/day

Carbon Usage (liquid-phase) for TCE row (Table B-2) =

88.5 lb TCE/day / 0.028 lb TCE / lb carbon = 3,161 lb carbon/day
2.7 lb TCE/day / 0.007 lb TCE / lb carbon = 386 lb carbon/day

----

3,547 lb carbon/day

APPENDIX C

COST COMPARISON SUMMARY

TABLE C-1
COST SUMMARY COMPARISON FOR RSA-95 AND RSA-96 GROUNDWATER REMEDIATION ALTERNATIVES
Redstone Arsenal, Madison County, Alabama

Project-772650-15
KT - RS95sum4 - 08/18/99

One 350 gpm GROUNDWATER TREATMENT STREAM				
RELEVANT DETAILED TABLES	TABLES C-2, C-3	TABLES C-4, C-5	TABLES C-6, C-7	TABLES C-8, C-9
COST COMPONENTS	AIR STRIPPING AND VAPOR-PHASE CARBON ADSORPTION ALTERNATIVE 1	AIR STRIPPING AND UV-CATALYTIC OXIDATION AIR EMISSION ALTERNATIVE 2	UV-PEROXIDE OXIDATION AND AIR STRIPPING TREATMENT ALTERNATIVE 3	UV-OZONE OXIDATION AND AIR STRIPPING TREATMENT ALTERNATIVE 4
INSTALLED CAPITAL COST (A)	$924,300	$1,576,600	$1,168,300	$1,631,700
UNIFORM COST EVALUATION BASIS FOR OPERATION AND MAINTENANCE (YEARS)	5	5	5	5
ANNUAL OPERATION & MAINTENANCE	$600,500	$463,900	$715,600	$638,500
NET PRESENT VALUE COST (B) (a) OPERATION & MAINTENANCE (O&M)	$2,805,600	$2,167,400	$3,343,300	$2,983,100
DELIVERY FOR PRIMARY EQUIPMENT	8 to 9 weeks	12 to 14 weeks	9 to 10 weeks	18 weeks
TOTAL NET PRESENT VALUE (A+B)	**$3,729,900**	**$3,744,000**	**$4,511,600**	**$4,614,800**

INFLATION	4%
INTEREST	5%

a. Net Present Values for the remediation alternatives are based on 4% inflation, and 5% interest rate.

b. System foundation, metal removal, main electrical distribution, and final effluent discharge piping to the Outfall are not included in the cost estimates.

c. System costs are based on the worst scenario of 350 gpm and 31 mg/L of TCE concentration.

Table C-2
Alternative 1 Preliminary Installation Cost Estimate for Air Stripping with Vapor-Phase Carbon Adsorption Treatment System
RSA-95 and 96, Redstone Arsenal, Madison County, Alabama

Project-772650-15
KT - Redsto95-95co4 - 08/18/99

COST COMPONENT	DESCRIPTION	COST ($)
DIRECT CAPITAL COSTS		
1. Site Preparation		15,000
2. Equalization Tank and Ancillary Items	20,000 gallons FRP tank, level transmitter etc.	38,000
Final Effluent CS Tank and Pump Skid	Pump is rated for 1,000 gpm, 40 Hp	58,000
3. Groundwater extraction well pumps (6)	Three vertical wells for RSA-95, and	30,000
Well pumps installation	three vertical wells for RSA-96	24,000
4. Air Stripper System (Shallow Tray)	One Skid-Mounted System rated for 350 gpm, 40 Hp, 3,500 scfm blower	108,000
5. Liquid-Phase Polishing Carbon Columns (for 350 gpm flow)	2 Dual-Bed Skid-Mounted Systems, including 4,000 lbs of carbon per column	NI
Carbon test for disposal (one time fee)		NI
6. Piping system and foundation	3", 4" and 6" diameter piping (underground construction cost is included)	NI
Foundation and sump	New pad for treatment systems	NI
7. Suspended solids removal system	Including filtering system	NI
Suspended solids removal test	Bench-scale test	NI
8. Vapor-Phase Carbon Columns (12' x 8' x 7' H) (for 3,500 cfm air flow)	Two Skid-Mounted Systems in series, including 15,000 lbs of carbon per system	98,000
Carbon test for disposal (one time fee)		1,200
9. Operation and Maintenance manual		25,000
10. Permit Application	Including air modelling	15,000
11. Process engineering design	Design Basis Manual	35,000
12. Installation		40,000
13. Electrical equipment (wiring installation)	Including telemanager monitoring system	NI
14. Procurement support		15,000
15. Report		20,000
16. Construction supervision and support		82,000
17. Shipping	Approximate	15,000
TOTAL DIRECT COSTS (TDC)		619,200
INDIRECT CAPITAL COSTS		
1. Engineering and related tech support	15 % TDC	92,900
2. Carbon Isotherm Test	for carbon loading	NI
3. Insurance and Bonds	5 % TDC	31,000
4. License, Permit, and Legal Fees	2 % TDC	12,400
5. Start-up (sampling costs are not included)		45,000
6. Contingency	20 % TDC	123,800
TOTAL INSTALLED COST (+50%, -30%)		924,300

NA - Not applicable
NI - Not included

Table C-3

Alternative 1 Cost Estimate for the Operation and Maintenance of Air Stripping with Vapor-Phase Carbon Adsorption Treatment System RSA-95 and 96, Redstone Arsenal, Madison County, Alabama (Based on Calgon Carbon Corp. Proposal, December 08, 1998)

Initial Capital Cost for 1 of 350 gpm System = $924,300

Project-772650-15

KT - Redsto95-95co4 - 08/18/99

COST COMPONENT	UNIT COST ($)	UNIT	QTY	UNITS/ PERIOD	ANNUAL COST ($)
1. Operating labor (a)	50	hour (hr)	16	hours per week	41,600
2. Monitoring labor	50	hr	0	hours per month	NI
3. Maintenance - Liquid-phase C	4,800	system/yr	0	system	NI
Vapor-phase carbon (C)	1,500	system/ex	12	exchange (ex)	18,000
Air stripper cleaning (2/year)	5,000	system/wash	2	wash / year	10,000
4. Materials					
. Liquid-phase carbon (b)	1.54	$/lb	0	lbs/day	NI
. Vapor-phase carbon (b)	1.61	$/lb	430	lbs/day	252,700
5. Utilities					
. Electric Power - Inlet Pumps	0.08	kwhr	895	kwhr/day	26,100
- Air stripper system (1)	0.08	kwhr	1,522	kwhr/day	44,400
- Vapor-phase carbon fan	0.08	kwhr	0	kwhr/day	0
6. Disposal (carbon shipping fee)	0.14	$/lb	12,900	lbs/month	21,700
7. Purchased services:					
Water samples analyses	350	Sample	5	samples/month	21,000
Vapor samples analyses	400	Sample	4	samples/month	19,200
(System monitoring only)					
8. Data evaluation	100	hr	40	hr/ 3 months	16,000
9. Quarterly report	8,000	Report	4	report / year	32,000
10. Project management	100	hr	20	hr/ month	24,000
TOTAL OPERATING COST					526,700
1. Insurance, permits, taxes	4% operating				21,100
2. Rehabilitation costs (c)					NA
3. Periodic site review					NI
4. Contingency	10% operating				52,700
TOTAL ANNUAL OPERATING COST (+50%, -30%)					600,500

a. Operator is required to check system twice per week (at 8 hours/trip)

b. Costs include carbon purchase, shipping charge, and spent carbon exchange for reactivation.

c. Replacement of mechanical components every 10 years.

NA - Not applicable. NI - Not included.

Table C-4

Alternative 2 Preliminary Installation Cost Estimate for Air Stripping with UV-Catalytic Oxidation Air Emission Treatment System RSA-95 and 96, Redstone Arsenal, Madison County, Alabama

Project-772650-15

KT - Redsto95-95co4 - 08/18/99

COST COMPONENT	DESCRIPTION	COST ($)
DIRECT CAPITAL COSTS		
1. Site Preparation		15,000
2. Equalization Tank and Ancillary Items	20,000 gallons FRP tank, level transmitter etc.	38,000
Final Effluent CS Tank and Pump Skid	Pump is rated for 1,000 gpm, 40 Hp	58,000
3. Groundwater extraction well pumps (6)	Three vertical wells for RSA-95, and	30,000
Well pumps installation	three vertical wells for RSA-96	24,000
4. Air Stripper System (Shallow Tray)	One Skid-Mounted System rated for 350 gpm, 40 Hp, 3,500 scfm blower	108,000
5. Liquid-Phase Polishing Carbon Columns (for 350 gpm flow)	2 Dual-Bed Skid-Mounted Systems, including 4,000 lbs of carbon per column	NI
Carbon test for disposal (one time fee)		NI
6. Piping system and foundation	3", 4" and 6" diameter piping (underground construction cost is included)	NI
Foundation and sump	New pad for treatment systems	NI
7. Suspended solids removal system	Including filtering system	NI
Suspended solids removal test	Bench-scale test	NI
8. Vapor-Phase UV-Catalytic Oxidation (for 3,500 acfm air flow/system)	Three Skid-Mounted Systems, each system contains approximately 108 UV lights	505,000
9. Operation and Maintenance manual		30,000
10. Permit Application	Including air modelling	15,000
11. Process engineering design	Design Basis Manual	40,000
12. Installation		45,000
13. Electrical equipment (wiring installation)	Including telemanager monitoring system	NI
14. Procurement support		20,000
15. Report		20,000
16. Construction supervision and support		100,000
17. Shipping	Approximate	20,000
TOTAL DIRECT COSTS (TDC)		1,068,000
INDIRECT CAPITAL COSTS		
1. Engineering and related tech support	15 % TDC	160,200
2. Carbon Isotherm Test	For carbon loading	NI
3. Insurance and Bonds	5 % TDC	53,400
4. License, Permit, and Legal Fees	2 % TDC	21,400
5. Start-up (sampling costs are not included)		60,000
6. Contingency	20 % TDC	213,600
TOTAL INSTALLED COST (+50%, -30%)		1,576,600

NA - Not applicable

NI - Not included

Table C-5

Alternative 2 Cost Estimate for the Operation and Maintenance of Air Stripping with UV-Catalytic Oxidation Air Emission Treatment System RSA-95 and 96, Redstone Arsenal, Madison County, Alabama

Initial Capital Cost for 1 of 350 gpm System = $1,576,600

Project-772650-15
KT - Redsto95-95co4 - 08/18/99

COST COMPONENT	UNIT COST ($)	UNIT	QTY	UNITS/ PERIOD	ANNUAL COST ($)
1. Operating labor (a)	50	hour (hr)	24	hours per week	62,400
2. Monitoring labor	50	hr	0	hours per month	NI
3. Maintenance - UV systems	4,000	system/yr	3	system	12,000
- UV lamps replacement	42	$/lamp	972	system	40,800
- Air stripper cleaning (2/year)	5,000	system/wash	2	wash / year	10,000
4. Materials					
. Liquid-phase carbon (b)	1.54	$/lb	0	lbs/day	NI
. Caustic (50%)	0.20	$/lb	290	lbs/day	21,200
5. Utilities					
. Electric Power - Inlet Pumps	0.08	kwhr	895	kwhr/day	26,100
- Air stripper systems (2)	0.08	kwhr	1,522	kwhr/day	44,400
- UV Oxidation Blower (2)	0.08	kwhr	0	kwhr/day	0
- UV Oxidation Light (60W) 3	0.08	kwhr	467	kwhr/day	13,600
- Scrubber systems (2)	0.08	kwhr	251	kwhr/day	7,300
6. Disposal (carbon shipping fee)	0.10	$/lb	0	lbs/month	0
7. Purchased services:					
Water samples analyses	350	Sample	5	samples/month	21,000
Vapor samples analyses	400	Sample	6	samples/month	28,800
(System monitoring only)					
8. Data evaluation	100	hr	40	hr/ 3 months	16,000
9. Quarterly report	8,000	Report	4	report / year	32,000
10. Project management	100	hr	20	hr/ month	24,000
TOTAL OPERATING COST					359,600
1. Insurance, permits, taxes	4% operating				14,400
2. Rehabilitation costs (c)					NA
3. Periodic site review					NI
4. Contingency	25% operating				89,900
TOTAL ANNUAL OPERATING COST (+50%, -30%)					463,900

a. Operator is required to check system 3 times per week (at 8 hours/trip)
b. Costs include carbon purchase, shipping charge, and spent carbon exchange for reactivation.
c. Replacement of mechanical components every 10 years.
NA - Not applicable. NI - Not included.

Table C-6
Alternative 3 Preliminary Installation Cost Estimates
of UV/Peroxide Oxidation and Air Stripping Treatment Systems
RSA-95 and 96, Redstone Arsenal, Madison County, Alabama

Project-772650-15

KT - Redsto95-95co4 - 08/18/99

COST COMPONENT	DESCRIPTION	COST ($)
DIRECT CAPITAL COSTS		
1. Site Preparation		15,000
2. Equalization Tank and Ancillary Items	20,000 gallons FRP tank, level transmitter etc.	38,000
Final Effluent CS Tank and Pump Skid	Pump is rated for 1,000 gpm, 40 Hp	58,000
3. Groundwater extraction well pumps (6)	Three vertical wells for RSA-95, and	30,000
Well pumps installation	three vertical wells for RSA-96	24,000
4. Air Stripper System (Shallow Tray)	One Skid-Mounted System rated for 350 gpm, 25 Hp, 2,400 scfm blower	86,000
5. Piping system and foundation	3", 4" and 6" diameter piping (underground construction cost is included)	NI
Foundation and sump	New pad for treatment systems	NI
6. UV/Peroxide Skid-Mounted System	One 350 gpm, 180 kw lamp (12 of 15 kw), Hydrogen Peroxide Dosing System	260,000
7. Residual Peroxide Decomposition System	Hydrogen Peroxide Decomposition System	NI
8. Suspended solids removal system	Simple filtering system	25,000
Suspended solids removal test	Bench-scale test	NI
9. UV System feed Pump	One 350 gpm pump (20 Hp)	6,000
10. Operation and Maintenance manual		25,000
11. Process engineering design	Design Basis Manual	35,000
12. Installation		35,000
13. Permit Application	Including air modelling	15,000
14. Electrical equipment (wiring installation)	Including telemanager monitoring system	NI
15. Procurement support		15,000
16. Report		20,000
17. Construction supervision and support		82,000
18. Shipping	Approximate	15,000
TOTAL DIRECT COSTS (TDC)		784,000
INDIRECT CAPITAL COSTS		
1. Engineering and related tech support	15 % TDC	117,600
2. Bench-Scale Test	For UV lights and chemical dosage	10,000
3. Insurance and Bonds	5 % TDC	39,200
4. License, Permit, and Legal Fees	2 % TDC	15,700
5. Start-up (sampling costs are not included)		45,000
6. Contingency	20 % TDC	156,800
TOTAL INSTALLED COST (+50%, -30%)		1,168,300

NA - Not applicable

NI - Not included

Table C-7
Alternative 3 Cost Estimate for the Operation and Maintenance of UV/Peroxide Oxidation and Air Stripping Treatment Systems RSA-95 and 96, Redstone Arsenal, Madison County, Alabama (Based on Calgon Carbon Corp. Proposal December 08, 1998)

Initial Capital Cost for 1 of 350 gpm System = $1,168,300

Project-772650-15
KT - Redsto95-95co4 - 08/18/99

COST COMPONENT	UNIT COST ($)	UNIT	QTY	UNITS/ PERIOD	ANNUAL COST ($)
1. Operating labor (a)	50	hour (hr)	24	hours per week	62,400
2. Monitoring labor	50	hr	0	hours per month	NI
3. Maintenance - UV/Peroxide	5,000	system/yr	1	system	5,000
- Air stripper cleaning (2/year)	4,000	system/wash	2	wash / year	8,000
4. Materials					NA
- Hydrogen Peroxide (50 %)	0.34	$/pound	1492	lb/day	185,100
One system			149	gal/day	
- Lamps (15 kW) replacements	845	$/lamps	36	lamps/yr	30,400
5. Utilities					
. Electric Power - Inlet pumps	0.08	kwhr	895	kwhr/day	26,100
- UV Lamps (12 x 15 kw)	0.08	kwhr	4,320	kwhr/day	126,100
- Air stripper systems (1)	0.08	kwhr	716	kwhr/day	20,900
- UV feed pump (1)	0.08	kwhr	358	kwhr/day	10,500
6. Purchased services:					
Water samples analyses	350	Sample	5	samples/month	21,000
Vapor samples analyses	400	Sample	2	samples/month	9,600
(System monitoring only)					
7. Data evaluation	100	hr	40	hr/3 months	16,000
8. Quarterly report	8,000	Report	4	report/year	32,000
9. Project management	100	hr	20	hr/month	24,000
TOTAL OPERATING COST					577,100
1. Insurance, permits, taxes	4% operating				23,100
2. Rehabilitation costs (b)					NA
3. Periodic site review					NI
4. Contingency	20% operating				115,400
TOTAL ANNUAL OPERATING COST (+50%, -30%)					715,600

a. Operator is required to check system 3 times per week (at 8 hours/trip)
b. Replacement of mechanical components every 10 years.
NA - Not applicable. NI - Not included.

Table C-8
Alternative 4 Preliminary Installation Cost Estimates of UV/Ozone Oxidation and Air Stripping Treatment Systems RSA-95 and 96, Redstone Arsenal, Madison County, Alabama

Project-772650-15
KT - Redsto95-95co4 - 08/18/99

COST COMPONENT	DESCRIPTION	COST ($)
DIRECT CAPITAL COSTS		
1. Site Preparation		15,000
2. Equalization Tank and Ancillary Items	20,000 gallons FRP tank, level transmitter etc.	38,000
Final Effluent CS Tank and Pump Skid	Pump is rated for 1,000 gpm, 40 Hp	58,000
3. Groundwater extraction well pumps (6)	Three vertical wells for RSA-95, and	30,000
Well pumps installation	three vertical wells for RSA-96	24,000
4. Air Stripper System (Shallow Tray)	One Skid-Mounted System rated for 350 gpm, 25 Hp, 2,400 scfm blower	86,000
5. Piping system and foundation	3", 4" and 6" diameter piping (underground construction cost is included)	NI
Foundation and sump	New pad for treatment systems	NI
6. UV/Ozone Skid-Mounted System	One 350 gpm, 6.24 kw lamp (96 of 65 watt), with Ozone Generator	634,000
7. Residual Peroxide Decomposition System	Hydrogen Peroxide Decomposition System	NA
8. Suspended solids removal system	Simple filtering system	25,000
Suspended solids removal test	Bench-scale test	NI
9. UV System feed Pump	One 350 gpm pump (20 Hp)	6,000
10. Operation and Maintenance manual		30,000
11. Process engineering design	Design Basis Manual	40,000
12. Installation		40,000
13. Permit Application	Including air modelling	15,000
14. Electrical equipment (wiring installation)	Including telemanager monitoring system	NI
15. Procurement support		20,000
16. Report		20,000
17. Construction supervision and support		82,000
18. Shipping	Approximate	20,000
TOTAL DIRECT COSTS (TDC)		1,183,000
INDIRECT CAPITAL COSTS		
1. Engineering and related tech support	10 % TDC	118,300
2. Bench-Scale Test	For UV lights and ozone dosage	10,000
3. Insurance and Bonds	5 % TDC	59,200
4. License, Permit, and Legal Fees	2 % TDC	23,700
5. Start-up (sampling costs are not included)		60,000
6. Contingency	15 % TDC	177,500
TOTAL INSTALLED COST (+50%, -30%)		1,631,700

NA - Not applicable
NI - Not included

Table C-9
Alternative 4 Cost Estimate for the Operation and Maintenance of UV/Ozone Oxidation and Air Stripping Treatment Systems RSA-95 and 96, Redstone Arsenal, Madison County, Alabama (Based on US Filter/WTS Proposal July 1997)

Initial Capital Cost for 1 of 350 gpm System = $1,631,700

Project-772650-15

KT - Redsto95-95co4 - 08/18/99

COST COMPONENT	UNIT COST ($)	UNIT	QTY	UNITS/ PERIOD	ANNUAL COST ($)
1. Operating labor (a)	50	hour (hr)	24	hours per week	62,400
2. Monitoring labor	50	hr	0	hours per month	NI
3. Maintenance - UV/Ozone	6,000	system/yr	1	system	6,000
- Air stripper cleaning (2/year)	4,000	system/wash	2	wash / year	8,000
4. Materials					
- Lamps (65 W) replacements	50	$/lamps	288	lamps/yr	14,400
- Hydrogen Peroxide (50 %)	0.34	$/pound	829	lb/day	102,800
5. Utilities					
. Electric Power - Inlet pumps	0.08	kwhr	895	kwhr/day	26,100
- UV Lamps (each 96 x 65 W)	0.08	kwhr	150	kwhr/day	4,400
- Ozone Generator, Compressor	0.08	kwhr	5,371	kwhr/day	156,800
- Air stripper system (1)	0.08	kwhr	716	kwhr/day	20,900
- UV feed pump (1)	0.08	kwhr	358	kwhr/day	10,500
6. Purchased services:					
Water samples analyses	350	Sample	5	samples/month	21,000
Vapor samples analyses (System monitoring only)	400	Sample	2	samples/month	9,600
7. Data evaluation	100	hr	40	hr/3 months	16,000
8. Quarterly report	8,000	Report	4	report/year	32,000
9. Project management	100	hr	20	hr/month	24,000
TOTAL OPERATING COST					514,900
1. Insurance, permits, taxes	4% operating				20,600
2. Rehabilitation costs (b)					NA
3. Periodic site review					NI
4. Contingency	20% operating				103,000
TOTAL ANNUAL OPERATING COST (+50%, -30%)					638,500

a. Operator is required to check system 3 times per week (at 8 hours/trip)

b. Replacement of mechanical components every 10 years.

NA - Not applicable. NI - Not included.

Response to U.S. Environmental Protection Agency
Comments on
Draft Evaluation of Groundwater Treatment
Alternatives for RSA-95 and 96
Redstone Arsenal NPL Site, Alabama

General Comments

Comment 1: **The proposed Interim Removal Action (IRA) uses only three of the six existing extraction wells in the final groundwater extraction system. This proposal is presented without adequate hydrogeologic support. The goal of this program is to remove VOC mass and prevent off-site migration. To indicate how the goal of preventing off-site migration will be addressed, maps showing the extent of the plume, groundwater flow directions, sources, well locations, radii of influence for the extraction wells, and other features should be presented and evaluated. The three wells which would be omitted from this program have 2400 to 4800 µg/L TCE, and would therefore also contribute to mass removal. Evaluation of how many wells should be pumped and whether more wells are needed should be completed before the treatment system is sized.**

Response 1: Agreed. A re-evaluation of the pumping and analytical data has been conducted and all six of the extraction well installed in the bedrock will be used in the IRA. Pumping rates at the six extraction wells have been reevaluated to maximize the recovery of TCE and TCA but to prevent drawing the more contaminated portions of the TCE and TCA plumes in to areas of lower contamination. Tables 3 through 6 have been updated to reflect the new pumping rates. Figures 1-2 through 1-4 have been added to show the TCE plume and maximum drawdown observed during the pilot testing.

Comment 2: **Given the objective of mass removal, the treatment system will need to be adequately sized. In addition to questions over the appropriate number of extraction wells to use, the yields of the extraction wells are not defined. The projected yields listed in the work plan are based on 150 percent of the maximum achieved during step-drawdown tests, because the yields in those tests were limited by the available temporary treatment system. The risk in estimating yields is that the designed treatment system may prove to be under-sized, and therefore mass removal rates will be less than optimal. Questions regarding how many extraction wells should be used and their optimal yields should be reevaluated before proceeding with treatment system design.**

Response 2: Agreed. However, it is important to point out here that part of the findings of the well performance tests and discharge/concentration pumping (Q/[C]) test was that the bedrock aquifer was capable of producing very high yields.

During the drawdown tests pumping rates above approximately 100 gpm could not be used because at higher rates, concentrations of contaminants in groundwater would have been too high to be accepted by the water treatment plant. Drawdown of more than 1.5 feet was observed more than 290 feet from the pumping wells at RSA-96. Drawdown of about 1.5 feet was observed 450 feet from the pumping well at RSA-95. Because of the high yields and large radial influence observed, IT believes that the projected pumping rates could be attained. However, lower pumping rates will be used in several of the wells so that more contaminated portions of the TCE and TCA plumes will not be pulled away from the central portion of the contaminant plumes.

Comment 3: **The work plan describes how extracted groundwater will be treated to meet MCLs in the effluent. Since the effluent will be discharged to Huntsville Spring Branch, it would be more appropriate to estimate the appropriate NPDES discharge requirements and describe how groundwater will be treated to meet those requirements.**

Response 3: A NPDES discharge permit application has been submitted for the proposed outfall. If discharge limitations in the permit are more stringent than the Federal MCLs then additional residence time in the air stripper or an additional parallel treatment train may be required. Additional treatment equipment or increasing residence times will not significantly alter the type of treatment selected.

Specific Comments

Comment 1: **Page 1-2, First Paragraph. The text asserts that groundwater extraction and treatment is not necessary at RSA-97, based on review of "secondary bedrock monitoring well data." The decision not to remediate groundwater at this degreaser site warrants discussion in the text. The data supporting this decision should be provided or cited.**

Response 1: Analysis and interpretations of the RSA-97 groundwater analytical data is in progress. Data concerning RSA-97 is being presented in a Report of Findings document, separate from this submittal.

Comment 2: **Page 1-2, Third and Fourth Paragraphs. The pumping rates during the step drawdown tests were limited by the hydraulic capacity of the treatment system. To compensate for this, the design pumping rates have been assumed at 150 percent of the maximum achieved during the step drawdown test. Treatment system design will be based on these**

assumed yields. The data supporting the assumed pumping rates should be presented for review. If there are significant questions about projected yield then the step drawdown tests should be redone. The consequences of not knowing maximum yield beforehand include possibly under-sizing the treatment system and once again being forced to accept yields (and mass removal rates) well below those that could be achieved.

It is difficult to understand why the projected yield for each extraction well was increased over each well's step drawdown test maximum by the same percentage. It is more likely that the discrepancy between the step drawdown result and the true maximum yield will vary from well to well. It is also difficult to understand why the maximum from the step test (as indicated on Table 1) varies from well to well; if the step-drawdown tests were limited by the hydraulic capacity of the temporary treatment system, the yield should be the same. These discrepancies should be explained.

Response 2: The primary objective of the IRA is to start reducing the mass of contaminants in groundwater in the most contaminated portion of the aquifer while other remedial actions are being investigated. Even though the pumping rates that were used in the well performance tests and in the Q/[C] tests did not exceed the specific capacity of the wells, the objectives of the testing were met.

The text does not convey all factors interpreted to limit the pumping rates. The limiting factors are the rate that groundwater could be fed to the pilot test treatment system and meeting the effluent waste acceptance requirements for the RSA sewer treatment plant. Groundwater containing higher TCE concentrations required treatment with a larger air to water ratio so that the removal rate would be higher, thus necessitating a lower pumping rate.

In addition, each test was conducted under different conditions, and the actual maximum pumping rate attainable from the well pump varied due to differences in the length of pipe and the number of joints to bring the water from the well to the air stripper. Nevertheless, the effect is the same; in all but one test the maximum pumping rate used did not draw the water level down below the top of the epikarst zone, and none of the tests exceeded the capacity of the well to yield water. The potential maximum pumping rate was not established for any of the wells. However, the tests did establish that the wells could be pumped at a high rate, and that pumping effects would be observed up to several hundred feet from the wells. Determining the maximum potential pumping rate is not the only objective of the pilot test. Determination of a proposed flow rate and concentration to the plant for TCE removal rate was achieved.

Concerning the projected yield, it is clear that the wells are capable of pumping at higher rates than used in the tests, and the upper bound was not determined. Furthermore, it is clear that the maximum potential pumping rate would not be approached during implementation of the IRA because drawdown effects were observed in monitoring wells up to several hundred feet from each well at the maximum individual test rates. So, estimated pumping rates half again higher than the highest rate used in the tests were used as a basis for sizing the treatment components. However, all of the installed wells will be used in the IRA.

Comment 3: **Section 1.2, page 1-3, first paragraph. Part of the goal of this program is to prevent off-site contaminant migration. The text goes on to say that the goal is not to control plume migration. It seems that preventing off-site migration will involve some level of plume control. This paragraph should be clarified.**

Response 3: The goal of the IRA is to begin reducing contaminant mass in the most contaminated portion of the aquifer. At this time it does not appear that the plume can be controlled hydraulically at the IRA stage. For this stage of the IRA, it is believed but not proven that the IRA system can reduce plume concentrations.

Comment 4: **Appendix A. Very high detection limits, from approximately 200 to over 2,000 µg/L, are reported for VOC concentrations in extraction wells. Further, results for only 12 VOCs are listed. Some of the parameters not listed, such as benzene and vinyl chloride, have low discharge limits and are closely related to parameters that were detected. The work plan should project whether these parameters will also meet their limits in the treatment system effluent streams.**

Response 4: Groundwater samples were collected, analyzed for, and reported following standardized EPA protocols. All compounds that are targets for EPA Method 8260A were analyzed for, but only compounds that were detected are listed in the analytical summaries in Appendix A. As noted, the high concentrations of TCE and TCA found in the groundwater samples result in elevated detection limits for most of the samples. Thus, the presence of minor components that may potentially be present are masked. However, benzene and vinyl chloride are not present in samples collected from the temporary treatment system effluent, analyzed at lower dilutions (typically 5 x or less). Therefore, if these compounds are present in groundwater, they are effectively removed via air stripping.

Comment 5: **Appendix B, Tables B-1 to B-4. Expected concentrations in the treatment stream for inorganic parameters are listed. No data are provided to support these weighted average concentrations. The units are listed in µg/L, but apparently some of the concentrations are in mg/L. Key design parameters such as iron, manganese, turbidity, and oil and grease were not reported. Concentrations of these parameters should be ascertained before proceeding with design. The background data base should be provided or described, and the units in the table should be revised.**

Response 5: Units will be revised in Tables B-1 to B-4. Water quality parameters will be addressed during the actual design phase. The evaluation was conducted to establish what treatment will be effective in addressing the primary contaminants TCE and 1,1,1-TCA.

Response to Alabama Department of Environmental Management,
Groundwater Branch Water Division
Comments on
Draft Evaluation of Groundwater Treatment
Alternatives for RSA-95 and 96
Redstone Arsenal NPL Site, Alabama

Summary

A review has been made of the referenced report. Based on this review, the following summary of the document and comments are given.

RSA-95 and RSA-96 are located within Operable Unit (OU-10) of Redstone Arsenal. Both sites were used in the manufacturing of rocket motors, which resulted in the release of trichloroethylene (TCE) and other chlorinated solvents to soils and subsequently to groundwater. As a consequence, large groundwater contamination plumes are present in vicinity of these sites. The concentration of TCE and other contaminants in the groundwater may exceed human health-based criteria and ecological criteria under certain exposure scenarios if remedial actions are not taken. Therefore, remedial actions are needed at these sites to reduce the concentrations of contaminants to acceptable levels.

Six (6) extraction wells have been installed at the two sites – 3 at RSA-95 and 3 at RSA-96. Sampling of these wells has found that 3 of these wells have 85% of the TCE and 60% of the trichloroethane (TCA) mass if pumped at a combined rate of 345 gallons per minute. The report recommends that these 3 wells be pumped at the suggested rate in order to maximize this interim remedial action while the entire OU is being investigated and prior to initiating the final remedial action.

Several treatment systems for the contaminated groundwater have been evaluated. As a result of this evaluation, it was determined that the most effective, lowest operating cost, and technically feasible treatment system is one that uses a centralized system with air stripping as the main treatment. Vapor-phase granular activated carbon will be used to control volatile organic compounds in the air stream in order to meet ADEM air regulatory requirements. An effluent discharge line will be needed to discharge treated groundwater to Huntsville Spring Branch where it will have to meet NPDES requirements.

Comment 1: **The final report should include a figure showing the area of investigation with the monitoring wells discussed in the report and previously generated maps showing contaminant concentrations at RSA-95 and RSA-96.**

Response 1: Agreed. Monitoring well and contaminant contour maps will be included in the final document.

Comment 2: **The report should include figures showing the estimated area of influence of the extraction wells under the various pumping conditions**

discussed i.e. the 755 gallons per minute (gpm) for all 6 extraction wells and the 345 gpm that the report recommends for this interim action.

Response 2: Additional figures will be added showing the estimated drawdown for the sites at the maximum pumping rates used during the pumping tests.

Comment 3: **The information generated as part of the well installation and pumping tests should be included with the report as well.**

Response 3: The pumping test data and interpretations have been issued in a results of testing report issued in June 1999 (IT, 1999a).

Comment 4: **The Conclusions and Recommendations section states that the groundwater recovery and treatment plant will be designed for greater than 350 gpm. Realizing that this is an interim action, it is recommended that the treatment plant be constructed such that additional capacity can be added in the event that groundwater monitoring reveals changes in contaminant plume shapes or concentrations from individual wells dramatically increase.**

Response 4: The treatment system pad will be designed so that additional treatment trains can be added if necessary.

Comment 5: **Wells in the vicinity of RSA-95 and RSA-96 should be put on a regular monitoring schedule as soon as practicable to monitor the influence of the extraction wells and the size and shape of contaminant plumes.**

Response 5: A water level monitoring and sampling plan developed for long-term operations of the OU-10 IRA is included in Appendix A of the IRA work plan OU-10 groundwater recovery and treatment system (IT, 1999b).

Comment 6: **The wells constructed as extraction wells but not currently used as part of the extraction and treatment system should remain functional and be sampled regularly to determine if they should be placed on-line to the treatment system.**

Response 6: Agreed. Text and computations will be revised using all six wells. All six extraction wells installed to date will be used in the IRA groundwater recovery system.

Response to U.S. Army Corps of Engineers
Comments on
Draft Evaluation of Groundwater Treatment
Alternatives for RSA-95 and 96
Redstone Arsenal NPL Site, Alabama

Comments by White, Geology

Comment 1: **I am very pleased to see someone finally using pump tests to design the chemical loading of the treatment system. Too many sites try to use monitoring well data which does not give a true picture of the site. Next time I would recommend letting one well pump for 72 hours and sampling every 8-12 hours after the first 16 hours.**

Response 1: Noted, suggestion will be incorporated as appropriate.

Comment 2: **Page 1-5. By the time the treatment plant comes on line you will need to chemically treat all of the extraction wells to remove the potential for biofouling. In addition, the costs for the pump and treat system will need to be adjusted to include quarterly-semiannual chemical treatment for all wells. The O & M plant or the plant should include a plan for all of the extraction wells.**

A draft version of EP 1110-1-27 "Operations and Maintenance of extraction/Injection Wells at HTRW Sites" is available on the HTRW-CX internal (USACE only) web site and has a good outline for such a plan.

Response 2: A monitoring and extraction well water level monitoring program and sampling plan will be incorporated into the Design Work Plan/Design Statement of Basis. Operational history since 1995 at OU-14 indicate that well fouling will not be a major problem.

Comments by Peterson, Estimation

Comment 1: **Each of the treatment alternatives (1-8) that are included in appendix B do not have a "write-up" describing the scope of the treatment process. Therefore it is very difficult to match the cost estimate to an alternative. Each alternative should be explained in adequate detail to compare the alternative with the estimated costs.**

Response 1: Process descriptions are provided in Section 1.4.1. The scope of all of the alternatives is the same: treat extracted groundwater and effluent vapors to meet discharge limitations.

Comment 2: **The document does not address the total cost of any alternative. Although some cost may be a constant for each alternative, the total cost should be communicated to the customer.**

Response 2: This document was prepared for the expressed purpose of deciding which groundwater treatment alternative should be selected. It is not an Engineering Evaluation and Cost Analysis. Selection is based on the relative cost differences and the ability of the process to achieve the discharge requirements for the IRA.

Comment 3: **The cost information presented in appendix b is summary information in nature. The cost could be reviewed if a complete scope for each alternative is provided with additional the cost back up that supports the summary level costs.**

The steps in developing a reviewable Remedy Cost Estimate are as follows.

1) **Define overall scope - define the project scope as completely as possible and clearly describe the underlying assumptions.**

2) **Identify cost elements - the cost elements used in appendix be are adequate for additional information on cost elements refer to the "Guide to documenting and managing Cost and Performance Information for Remediation Projects (EPA 542-B-98-007)**

3) **Estimate Quantities - Quantities are estimated for each cost element. The estimation of quantity for each element is critical in understanding the limitations of the estimate.**

4) **Estimate unit costs - Unit cost are again necessary for each cost element.**

5) **Add additional cost, such as contingency - Explanations for the additional cost should be included.**

Response 3: Only relative costs were compared, the Evaluation of Groundwater Treatment Alternatives was prepared to support selection of a treatment technology for an Interim Remedial Action, not to present a total capital cost. Elements of the cost estimates listed in Tables I-2 through I-9 are based on either previous construction, proposed costs obtained from venders for this project, or from Means tables.

Comments by Lien

Comment 1: **Table 1 & 2 add units, ug/L is what I assumed.**

Response 1: Units will be added as requested.

Comment 2: **Page 1-7. The loading rate assumes equilibrium concentrations are reached in the columns. I would add a big factor of safety into this evaluation. Also indicate where the 22,000 factor came from (what was the loading assumed expressed as "k" earlier)**

Response 2: "Loading rate" should read "carbon consumption rate". The factor of 22,000 is a conversion factor (correctly [2.2 lb/kg]/[1000 g/kg]). The text equation will be revised to reflect these changes.

Comment 3: **Page 1-7 para 1.4.1. The use of a non-UV lamp advance oxidation process should be evaluated. The system is designed using components off the shelf. Controls are quite simplified, no lamps to replace (the primary O & M cost). Typically lamps must be replaced annually or even more frequently dependant on the wattage. The higher the wattage, the lower the life.**

Response 3: Non-UV lamp advance oxidation process was evaluated. However, because the majority of non-UV lamps do not produce the correct wavelength in the spectrum of TCE effective photolytic reaction, UV technology was selected. The optimum TCE absorption spectra ranges from 200 to 240 nanometers (nm).

Comment 4: **Page 2-2. Need to look at the potential scavengers, especially iron and manganese which may require pretreatment.**

Response 4: Operational history at OU-14 indicates that scavenging will not be a problem. Iron and manganese will not be a potential problem for the treatment system (based on recent data [July 1999] from extraction wells groundwater). Iron and manganese concentrations were less than 4 mg/L and 0.3 mg/L, respectively.

Comment 5: **Page 2-2 para 2.1 Look at the carbon cost based on actual costs. If this is a short term RA, then phase transfer with regeneration would be a simple low cost option followed by Air Stripping. I am assuming about $0.75/ pound for GAC.**

Response 5: Agreed, carbon price was based on actual cost ($0.76 per pound for virgin carbon), excluding shipping and spent carbon exchange costs. Spent carbon will be regenerated at a RCRA reactivation facility.

Comment 6: **Page 2-3 para 2.2. I would recommend consulting with vendors, or using values in the literature if you are interested in some equilibrium concentrations. A mini column dynamic test by a vendor would be a better estimate of the GAC usage, and probably cost less, and take less time.**

Response 6: Agreed, a mini column dynamic test by a vendor would be required if liquid-phase carbon is selected as a preferred option.

Comment 7: **Appendix B. Some example calculations to verify the concept, and allow your customer and regulators to validate your methodologies, should be included in the document**

Response 7: Some example calculations will be incorporated to Appendix B. Detailed calculations will be incorporated to the design basis report.

Comments by Georgian, Chemistry

General **VOC analyses were performed using Method 8260A rather than 8260B (promulgated in 12/96). It appears that the analyses were performed in the summer and fall of 1998, well after the revised SW-846 method was promulgated. (The list of analytes for methods such as 8260B and 8270C are not well defined--it is expected that the SAP or QAPP will list the individual analytes for which quantitation is required.)**

Lastly (though not a significant deficiency), the preparatory method is not specified.

(Observation: Analytical methodology continues to be inadequately specified. The failure to use the most recently promulgated SW-846 methods is a repeat deficiency.)

Response: Method 8260A for volatile organic compounds is contractually specified for work at Redstone Arsenal.

Comment 1: **Table 2. The dilution factors and concentration units should be listed in Table 2. A footnote should list both the determinative and**

preparatory method and should specify whether 5-mL or 25-mL purges were performed. The reporting limits should be defined. The contaminant specific decision limits (e.g., risk based limits) should also be summarized in the table.

(Observation: The failure to define the reporting limit is a repeat deficiency.)

Response 1: Concentration units will be added to Table 2. The data presented in Table 2 was obtained from either the last sample collected from each well during the pumping tests or from the sample analyzed at the lowest dilution. Clarification will be added to Table 2.

The term "detection limit" in the text actually is the "reporting limit". The text will be revised.

Data qualifiers are available in the Analytical Summary Tables in Appendix A. Dilution factors can be inferred from the detection limits, e.g. where a compound normally has a reporting limit of 1 µg/L is reported as 2000 µg/L with a "U" qualifier, the sample was analyzed at a 1:2000 times dilution. Decision limits (discharge limitations in the text) are given in Tables 5 and 6 and presented in the context of the discussion of the results.

Comment 2: **Section 1.3. Section 1.3 should discuss how the analyte concentrations were determined. (For example, is the TCE concentration listed for well RS715 based upon a single analysis or multiple analyses?)**

Response 2: Concentrations given in Table 3 are from Table 2. Clarification will be added to Table 2.

Comment 3: **Table 5. The concentration of 1,1-dichlorethane is listed as "zero" Laboratories do not report zero concentrations but nondetections are specified to some reporting limit. A rationale for reporting the concentration as "zero" should be presented. Quantitation limits are not presented.**

(Observation: Method data quality of objectives for sensitivity continue to be poorly addressed.)

Response 3: Concentrations listed in Table 5 are weighted means of the reported concentrations in individual groundwater samples or individual treatment streams. Reported "zero" should be shown as follows 1,1 DCA; 0.46 at

RSA95 and "<400" at RSA 96, chloroform; "<400" at RSA 96, tetrachloroethene; 2 at RSA-95. However, for computation of the concentrations in the Treatment Streams the nondetections are treated as "zeros"

General **Since vinyl chloride is a potential breakdown product of TCE and it appears that vinyl chloride is being analyzed since "Method 8260A" is being used, it seems advisable to list a decision limit for vinyl chloride (even though vinyl chloride may not have been detected).**

Response: The decision limits, referred to as "Discharge Limitations" for compounds will be set by the NPDES permit. These limits are unavailable at the time of publication of this document.

Comment 4: **Table A-1 - A-6. Concentrations, units and dilution factors should be specified in Table A-1. Does the "U" qualifier actually refer to the detection limit or the reporting limit? The report should clarify. In addition, the report erroneously defines the J flag as follows: "Estimated concentrations below the detection limit." If a result is below the detection limit, by definition, a concentration---estimated or otherwise--cannot be reported as a detection. The criteria for the application of the B flag should also be discussed. For example, was the CLP or SW-846 blank acceptance criteria used? If the former, the report should discuss why (in terms of the objectives for the data) CLP criteria were applied to SW-846 methods? Lastly, the "D" qualify in Table A-6 is not defined.**

(Observation: The problem described above is indicative of a repeated failure to adequately address sensitivity.)

Response 4: The "U" indicates that there was no instrument response for the compound, and so was not detected. Where there was an instrument response, but it was less than the lowest calibration standard, a concentration was calculated assuming a linear concentration/response function, and is therefore an estimated concentration. The term "detection limit" will be replaced by "reporting limit" for clarity.

The "D" qualifier indicates that the compound was analyzed at a secondary dilution.